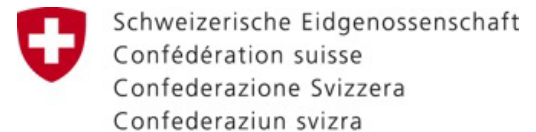




**SHARED VISION
FOR A RESILIENT FUTURE**

Workshop "Cryosphere and Economy: Water Resources, Agriculture, and Emergencies" at the Regional Ecological Summit (RES)

24.04.2026



Direktion für Entwicklung und Zusammenarbeit DEZA



Future Scenarios of Snow and Glaciers in Central Asia

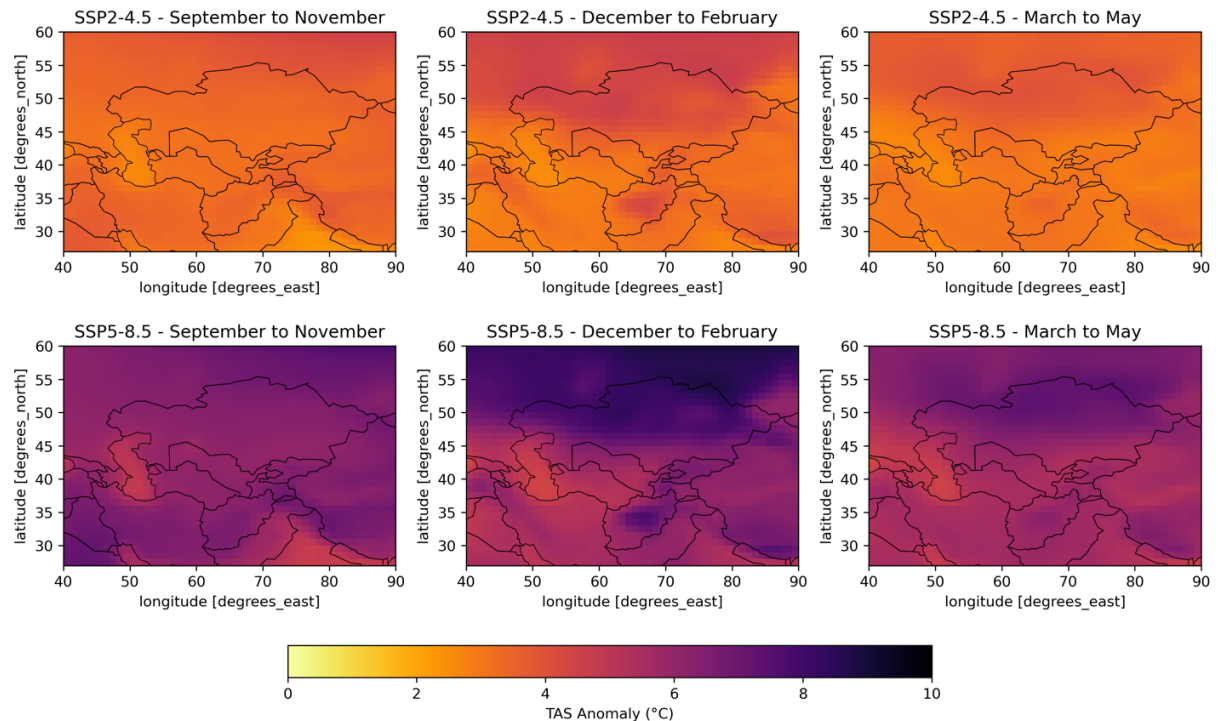
University of Fribourg & National Research Institutes in Central Asia



Future climate change- CMIP6 TAS

- Warming in all seasons, elevations and scenarios.
- Stronger warming in winter (DJF) at high elevations and latitudes.

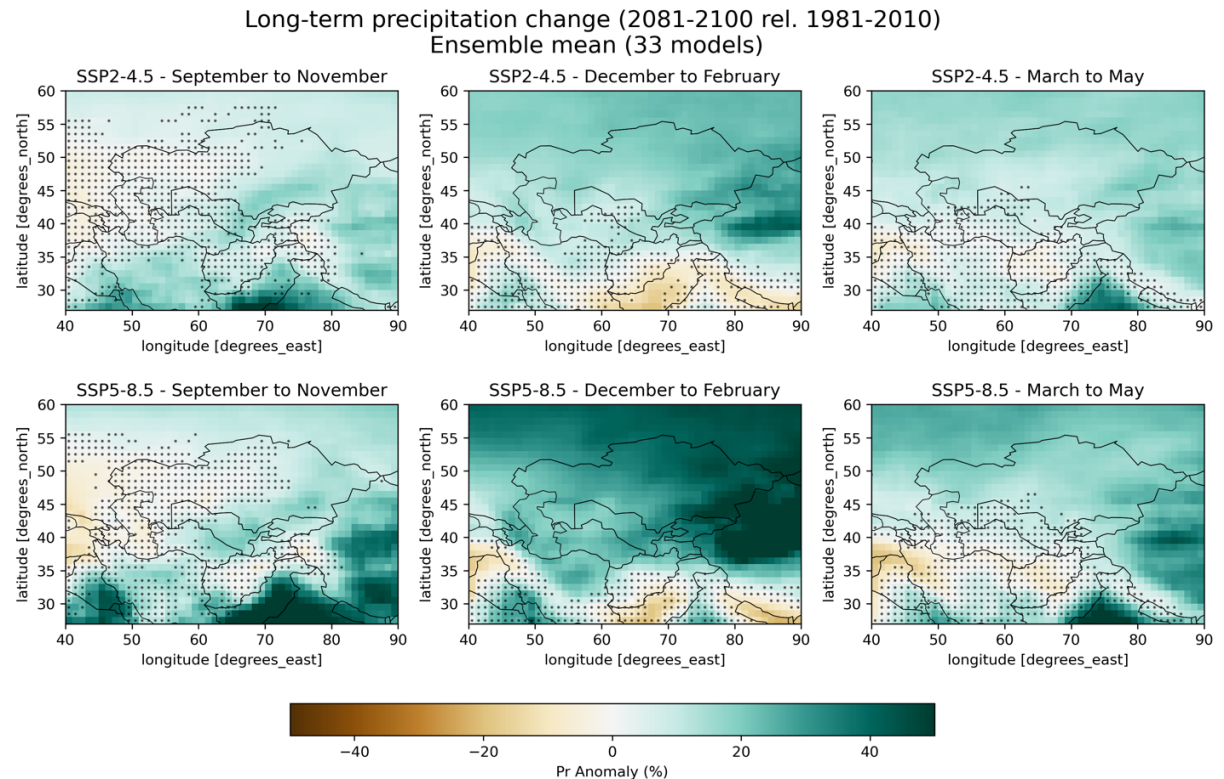
Long-term mean air temperature change (2081-2100 rel. 1981-2010)
Ensemble mean (34 models)



CMIP6 climate projections for near surface air temperature anomaly (TAS) over the model domains for moderate (SSP2-4.5) and high (SSP5-8.5) emission scenarios and three seasons (SON, DJF, MAM).

Future climate change- CMIP6 Pr

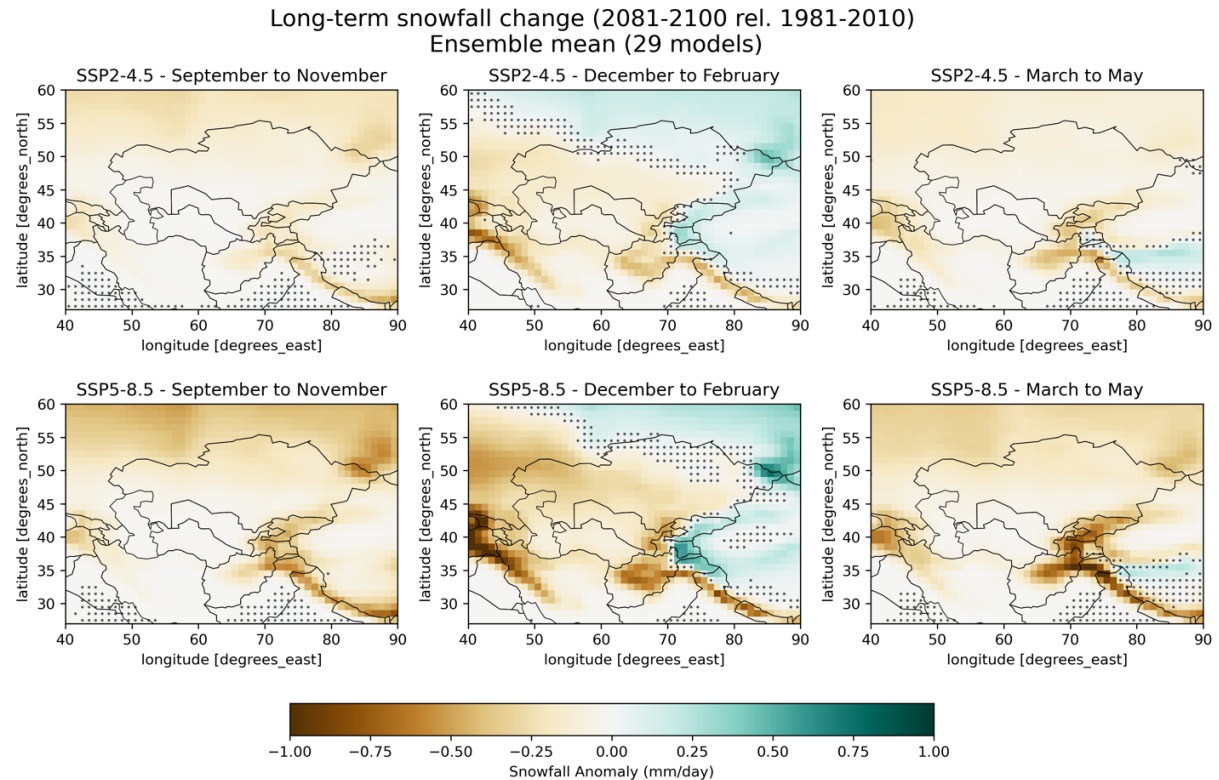
- Uncertainty in precipitation,
- Increased winter (DJF) precipitation in Northern Tien Shan and Tibetan Plateau and Eastern Pamir.



CMIP6 climate projections for precipitation anomaly (Pr) over the model domains for moderate (SSP2-4.5) and high (SSP5-8.5) emission scenarios and three seasons (SON, DJF, MAM).

Future climate change- CMIP6 Snowfall

- Reduced snowfall all regions in edge seasons of autumn (SON) and spring (MAM).
- Increased snowfall in winter (DJF) in high latitudes, Eastern Pamir, Northern Tien Shan.
- Very strong reduction in spring snowfall (MAM) in high emission scenario SSP5-8.5.



CMIP6 climate projections for snowfall over the model domains for moderate (SSP2-4.5) and high (SSP5-8.5) emission scenarios and three seasons (SON, DJF, MAM).

The cryosphere

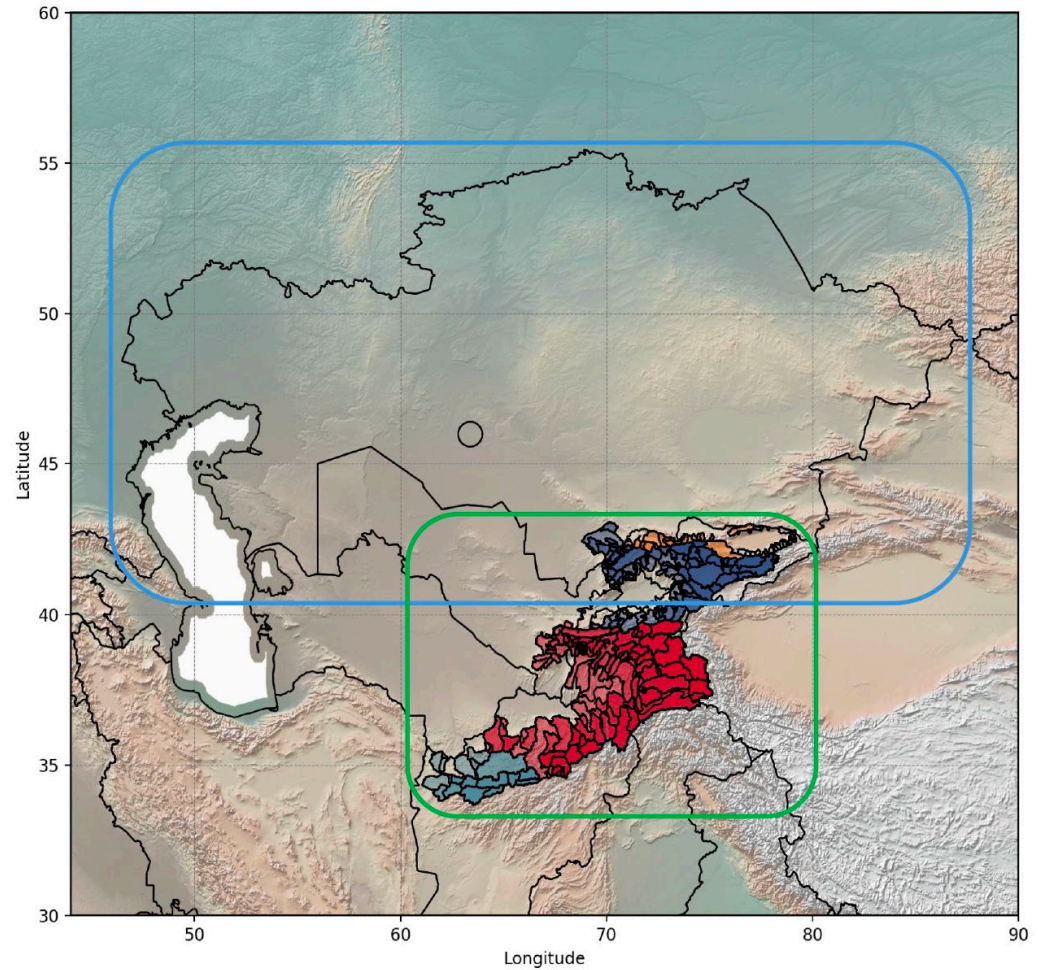


Modelling Future Snow Scenarios - Methods

- Step 1: TopoSUB – Topographical clustering – based on key topographic parameters such as elevation, slope, aspect, and sky view factor (Fiddes & Gruber, 2012)
- Step 2: TopoSCALE – Downscaling current climate - utilizing ERA5 reanalysis data, and adjusting to localized climate conditions by accounting for topographic effects such as altitude, exposure, and terrain-induced variations (Fiddes & Gruber, 2014).
- Step 3: TopoCLIM – Quantile mapping and bias correction of future scenarios - CMIP6 global climate model data statistically downscaled based on TopoSCALE baseline data.
- Step 4: Snow modelling and output generation - future climate data simulated in the snow model FSM (Essery 2015)

Methods

Overview map of the two modelling domains (1) High Mountain Central Asia (HMCA) (2) Kazakhstan (KAZ).

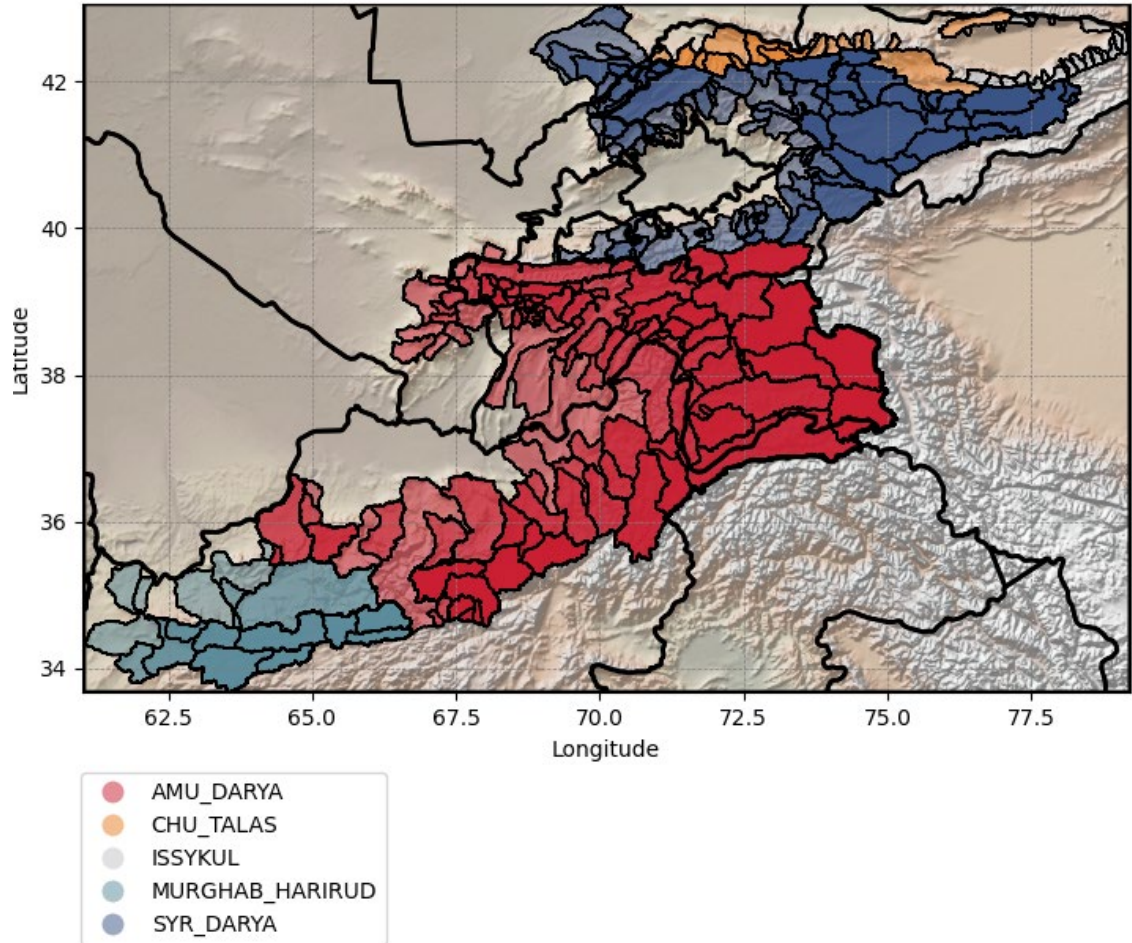


Methods

Model domain
High Mountain
Central Asia.

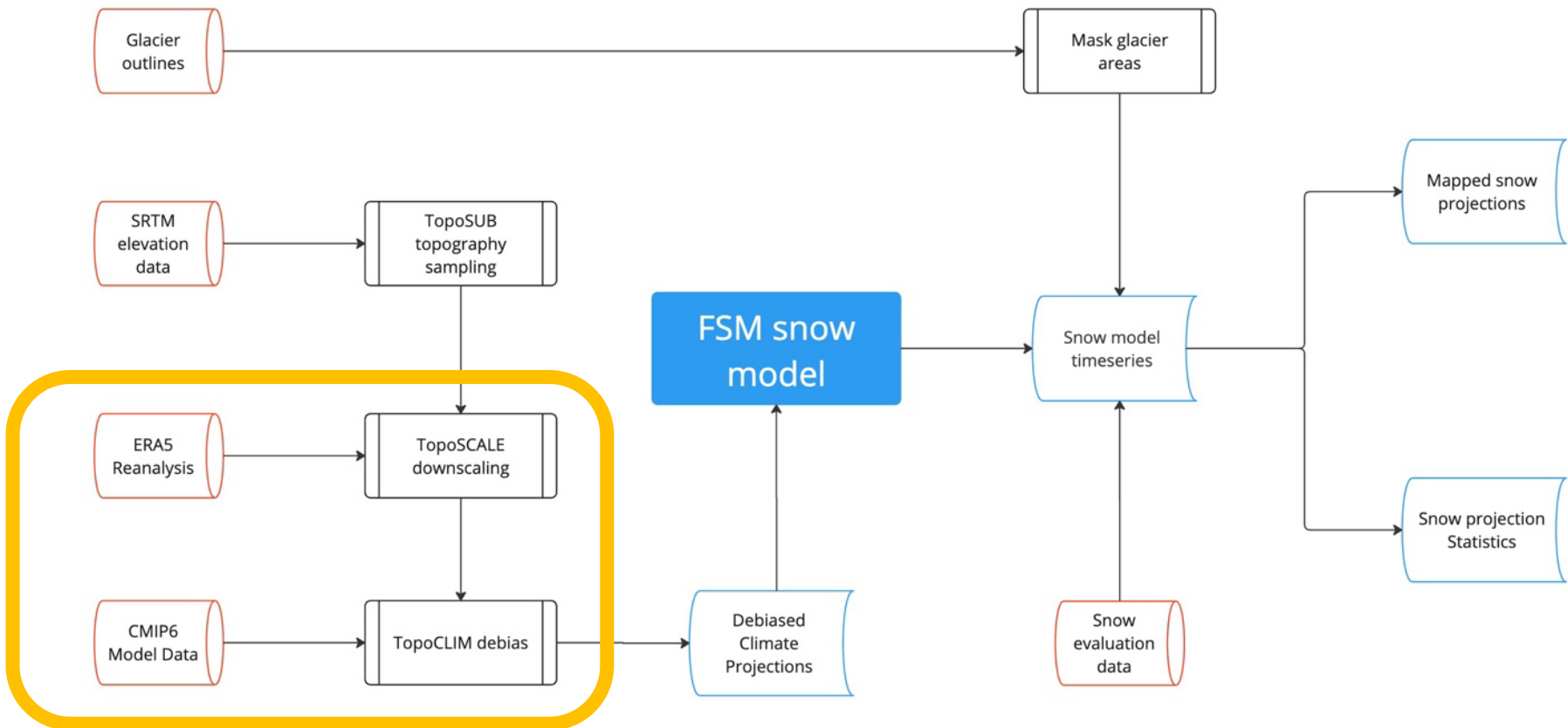
Analysis units:

- 211 catchments
- 5 basins

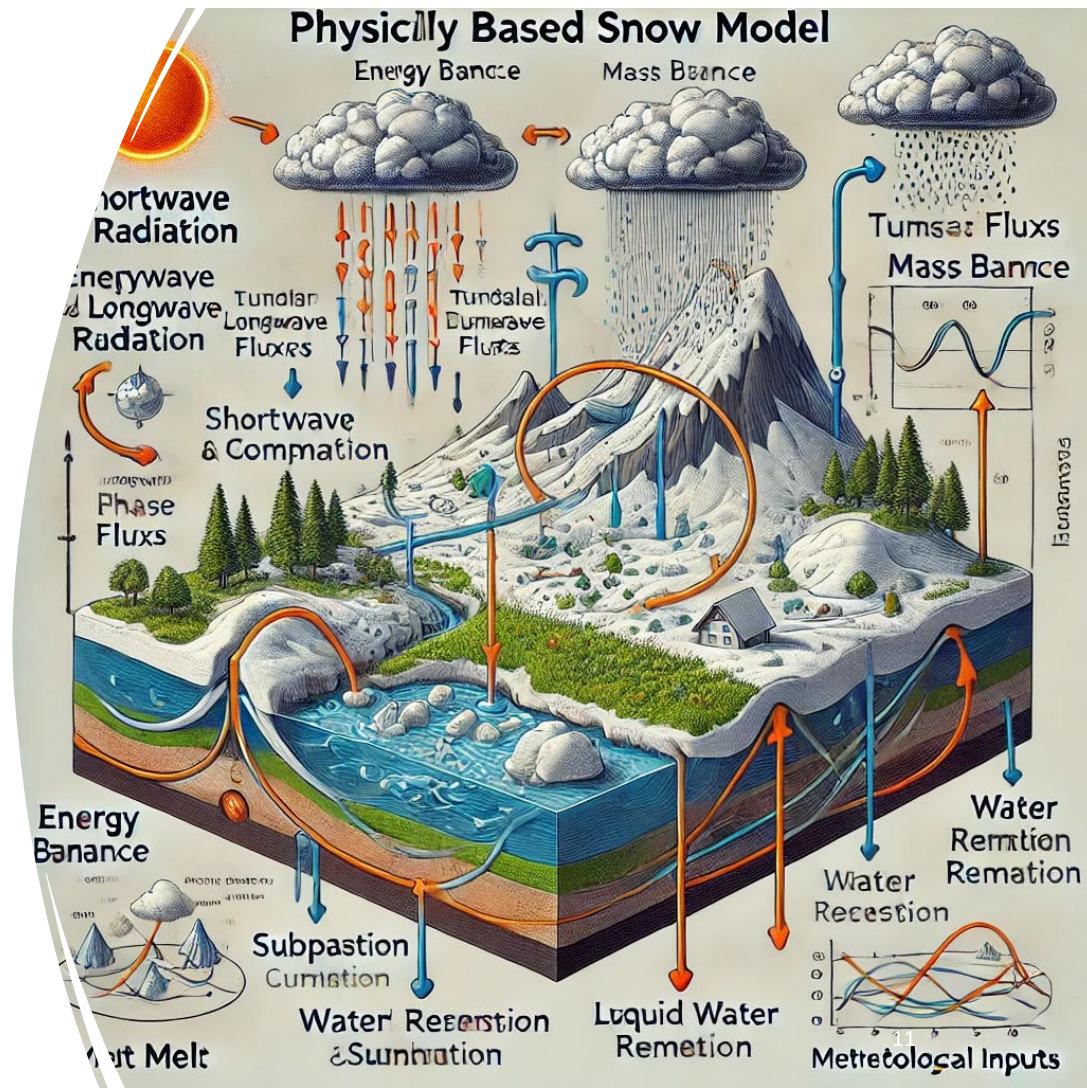


Climate Impact Model Chain

Quantile
mapping!



Physically-based snow modelling



Simulated Variables

The table below presents the key simulated variables used in the study. These include snow-related parameters such as **snow depth (snd)** and **snow water equivalent (SWE)**, which are essential for understanding snow accumulation and melt. Additionally, **albedo (alb)** represents the surface reflectivity and used as a proxy for snow cover in this study, while **runoff (Rof)** quantifies the total water runoff from snow and rain. The dataset also includes **surface temperature (Tsf)** and **soil temperature (Tsl)** at a depth of 20 cm, providing insights into energy balance and ground thermal conditions.

Variable	Units	Description
alb	-	Effective albedo
Rof	kg m ⁻²	Cumulated runoff from snow (including rain input)
snd	m	Average snow depth
SWE	kg m ⁻²	Average snow water equivalent
Tsf	°C	Average surface temperature
Tsl	°C	Average soil temperature at 20 cm depth

Models and Scenarios

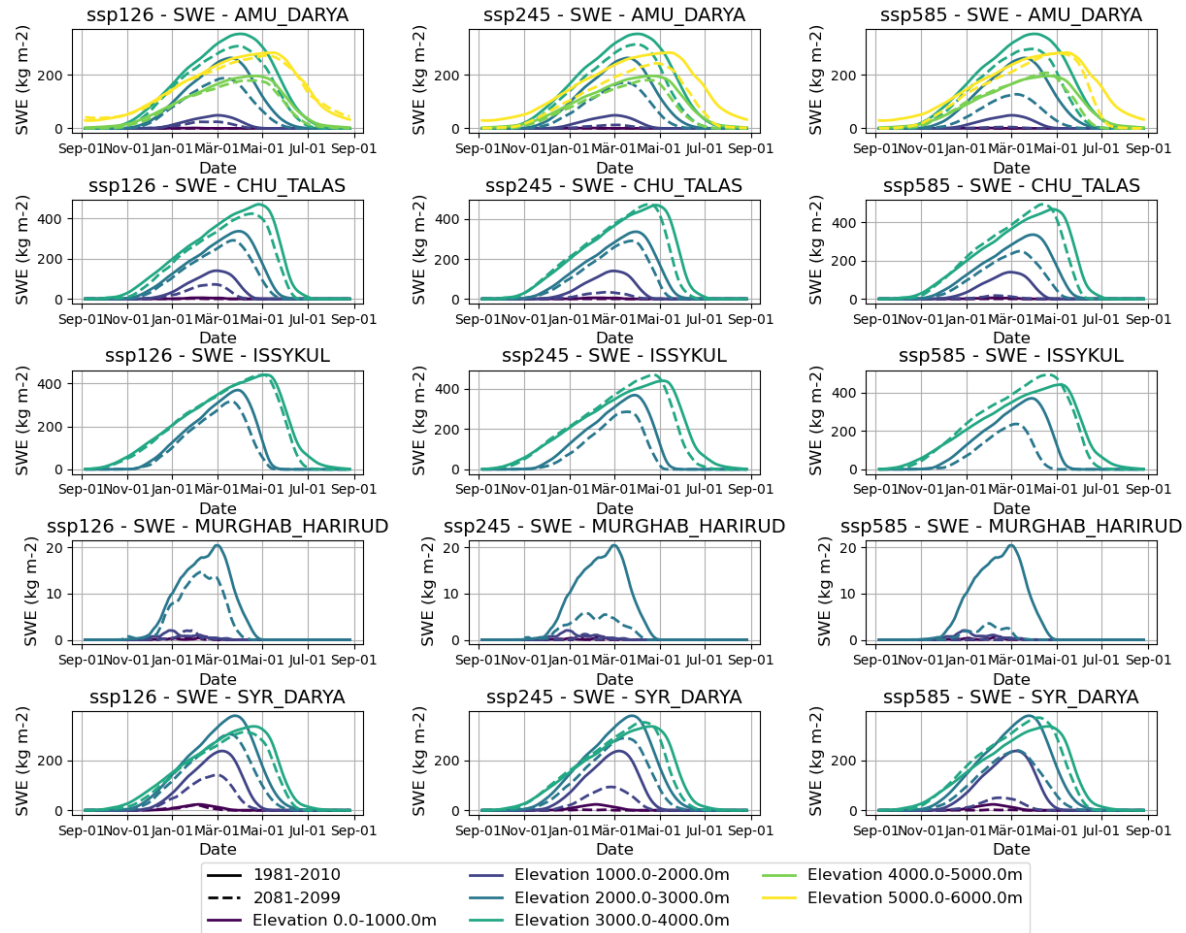
Climate models and scenarios used in this study:

- Historical: 1970-2015.
- Scenarios: 2015-2100
- Quantile mapping: 1995-2015

Model	Historical	SSP1-RCP2.6,	SSP2-RCP4.5	SSP3-RCP7.0	SSP5-RCP8.5
UKESM1.0-LL	X	X	X	X	X
GFDL-ESM2M	X	X	X	X	X
IPSL-CM5A-LR	X	X	X	X	X
MRI-ESM2-0	X	X	X	X	X

SWE

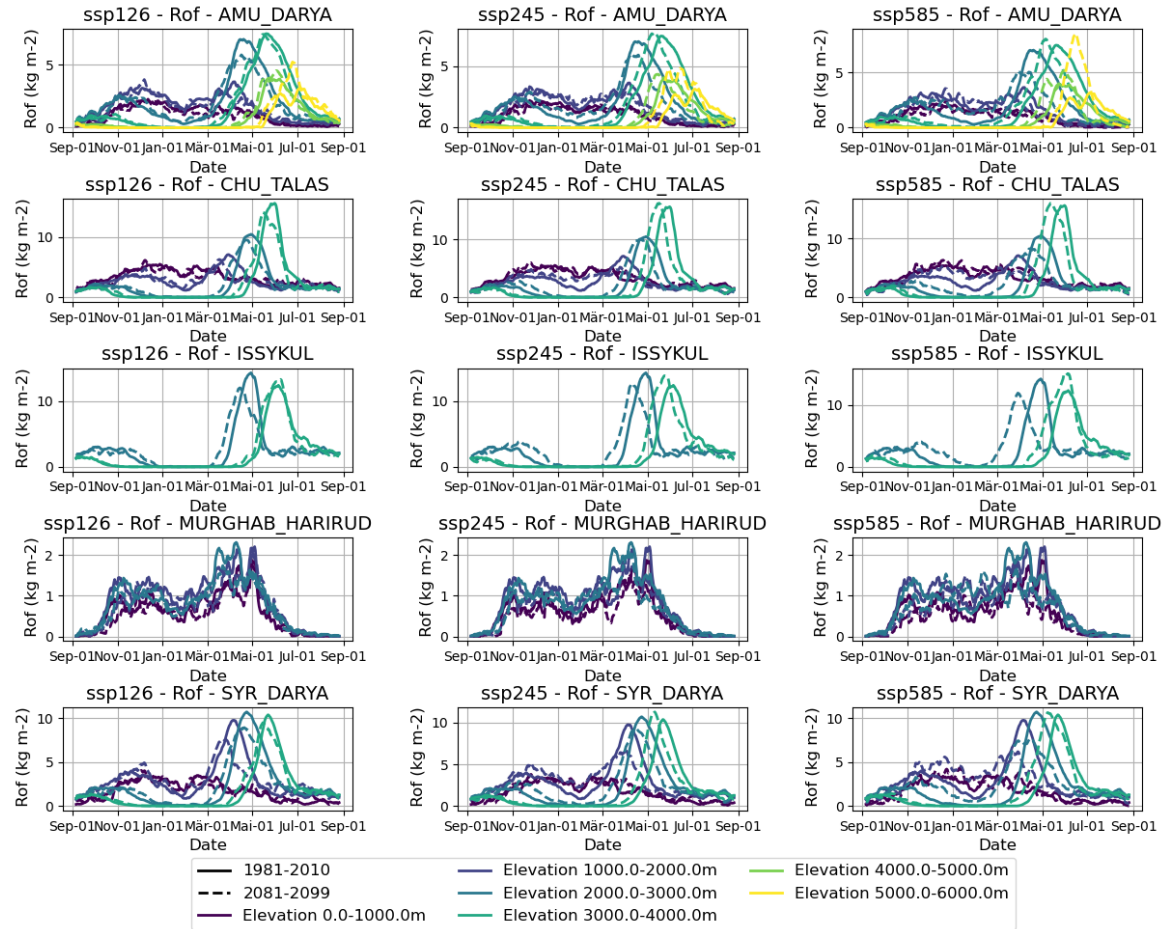
- Decrease SWE in all scenarios, elevations and regions.
- More frequently there occurs an earlier ablation of SWE in spring than delayed start of accumulation in winter.
- Highest values of SWE occur at 3000-4000m in the region



Seasonality of climate change for snow water equivalent (SWE) the far-future period (2081-2100) compared to the reference period (1981-2010). The analysis is conducted across three climate scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5. The results are visualized as average values for each period, spanning a full hydrological year (from September 1 to August 31 of the following

ROF

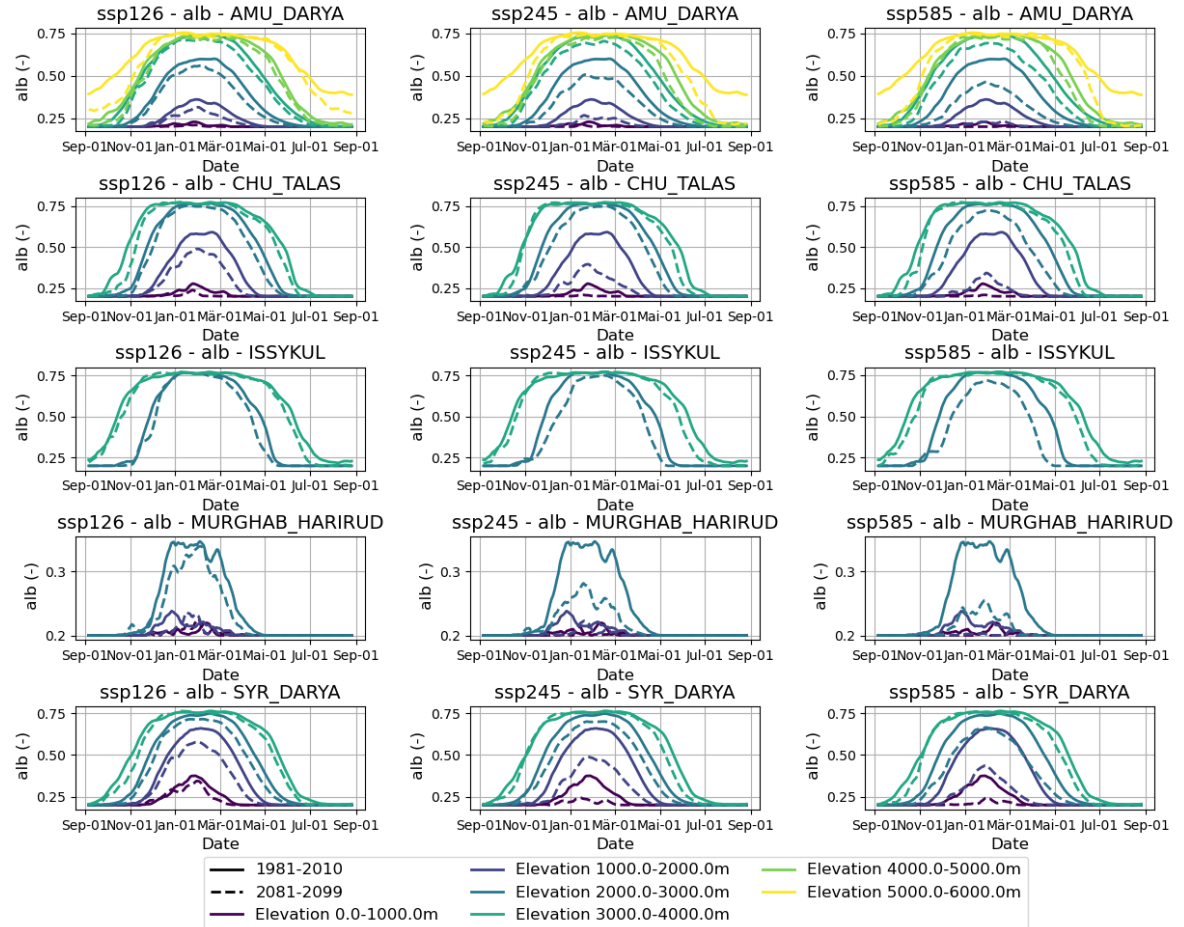
- Majority runoff is generated above 2000m in all regions
- Increase in highest elevation (5000m+) runoff in SSP5-8.5, due to increase in winter precipitation.
- Snowmelt peaks start and end earlier in season, with strength of effect increasing with emission scenario up to a month in the strongest emission scenarios.



Seasonality of climate change for snowmelt (Rof) the far future period (2081-2100) compared to the reference period (1981-2010). The analysis is conducted across three climate scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5. The results are visualized as average values for each period, spanning a full hydrological year (from September 1 to August 31 of the following year).

ALB

- Reduction in snow cover below 2000m strong in all scenarios and particularly non-existent in highest scenario.
- Decreases in albedo (representing snow cover) very strong below 2000m in Sry Darya and below 3000m in Amu Darya basin.



Seasonality of climate change for surface albedo (alb) the far-future period (2081-2100) compared to the reference period (1981-2010). The analysis is conducted across three climate scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5. The results are visualized as average values for each period, spanning a full hydrological year (from September 1 to August 31 of the following year).

Projected SWE changes in Syr-Darya basin and Amu-Darya - **Less snow in the reservoir**

- Peak snow water equivalent (SWE) declines sharply, with the critical **2000–3000 m melt zone** losing a third to a half of its peak under high emissions.
- The loss is strongly elevation-dependent: **below 2000 m snow largely disappears (–80 to –90%)**, while the highest elevations (>4000 m, Amu Darya) retain or even gain snow as precipitation increases in still sub-freezing air.

Basin	SSP1-2.6	SSP2-4.5	SSP5-8.5
Amu Darya	–27%	–34%	–51%
Syr Darya	–18%	–23%	–36%

Projected relative changes (%) under different climate scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) for the 2000–3000 m elevation band.

Projected snow melt changes in Syr-Darya basin and Amu-Darya - **Melt happens earlier**

- In the 2000–3000 m melt zone, **half the peak snowpack is gone ~2 weeks earlier** under SSP5-8.5:
- **Amu Darya:** half-melt shifts from **27 May → 15 May** (–12 days)
- **Syr Darya:** half-melt shifts from **29 May → 17 May** (–12 days)
- Peak **SWE** itself arrives ~10 days earlier in both basins.

Projected snow melt changes in Syr-Darya basin and Amu-Darya -**Runoff arrives \approx 3 weeks earlier**

- Runoff centroid (centre-of-mass timing) in the melt zone **shifts substantially earlier** under SSP5-8.5:
 - Amu Darya: **13 Apr \rightarrow 21 Mar** (~23 days earlier), annual total **-11%**
 - Syr Darya: **3 May \rightarrow 10 Apr** (~23 days earlier), annual total **+7%**
- Syr Darya gains slightly in total water, but the timing shift means **more water in late winter/early spring and less in the summer months** when irrigation demand peaks.

The cryosphere

MEASUREMENTS



Aerial surveys



Remote sensing

SELECTED PARAMETERS



Glacier surges



Glacier area, volume and length



Glacier mass balance



Glacier surveys, expeditions



Cameras and sensors on glaciers

DATA AND SERVICE USERS

Risk of glacial lake outburst floods (GLOFs)



Water inflow into reservoirs, hydropower planning



Water availability for crops



Glaciers

Glacier data and services span time horizons from days to decades.

Time horizon

Days

Seasons

Years

Decades



Supported by

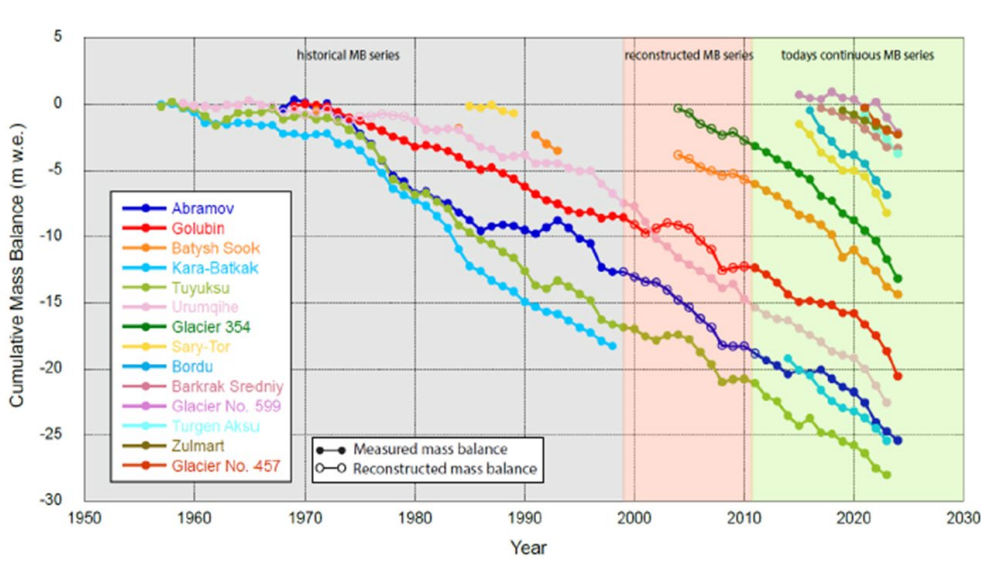
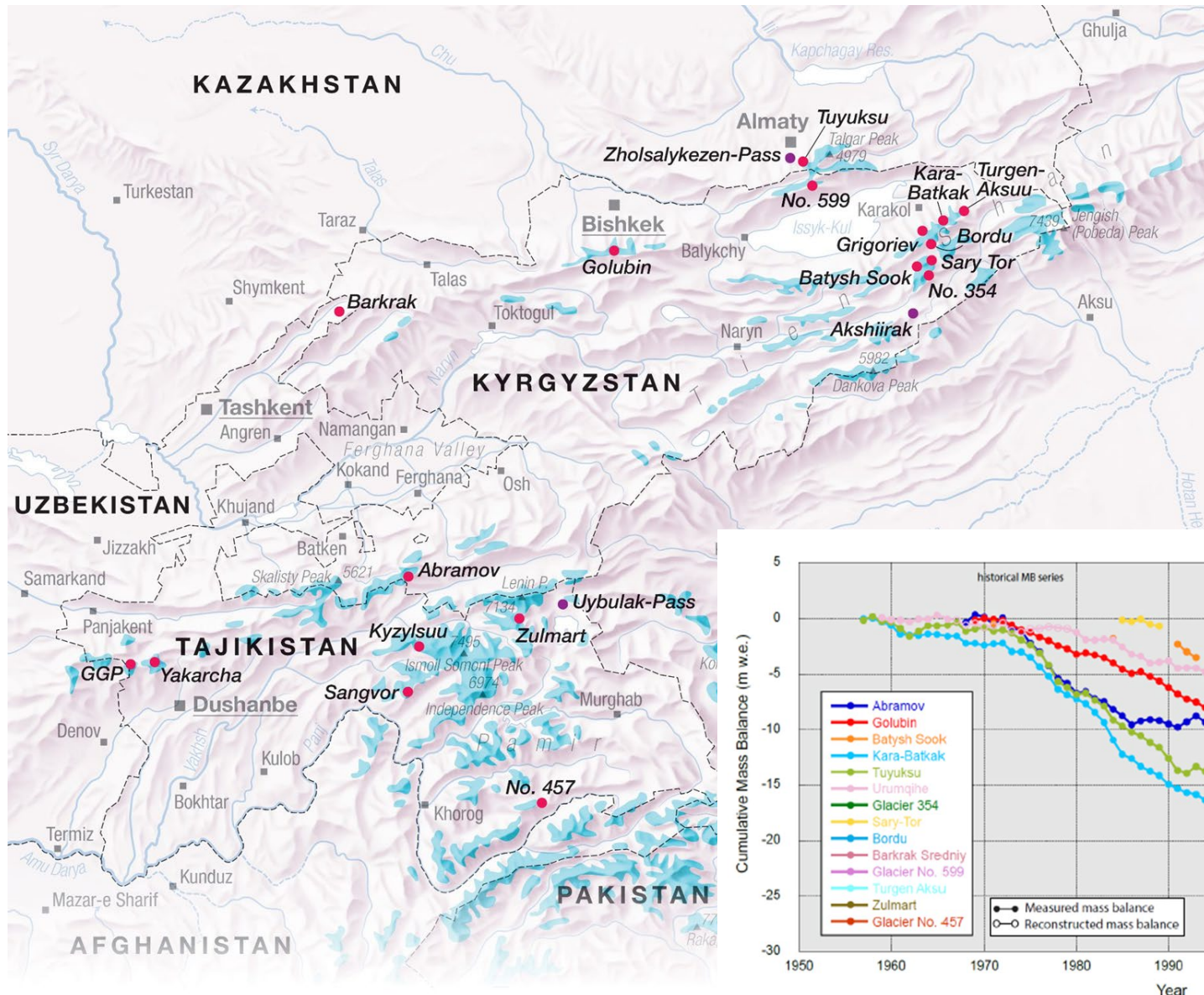


Produced by



From monitoring to resilience: Cryosphere information services in Central Asia

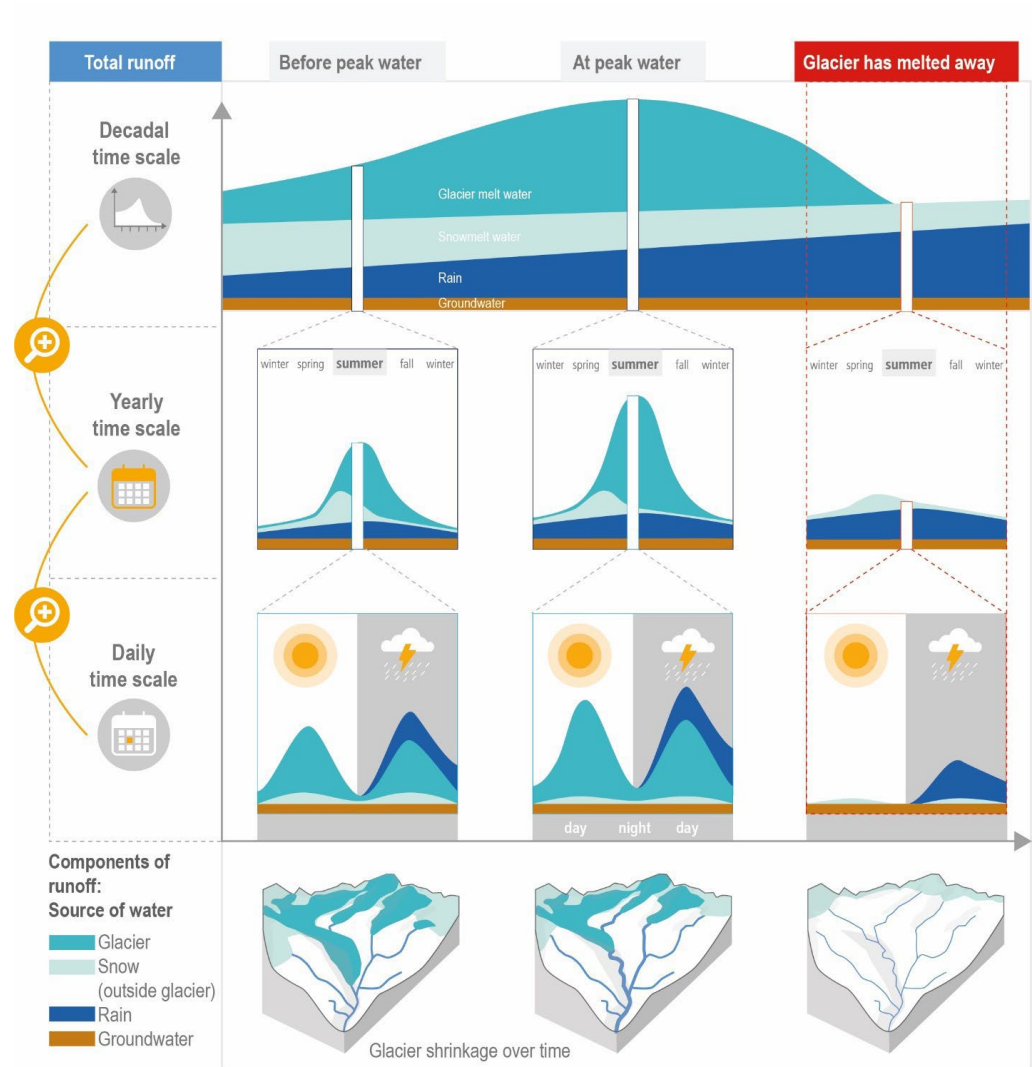
Glacier monitoring network



Barandun et al. 2026

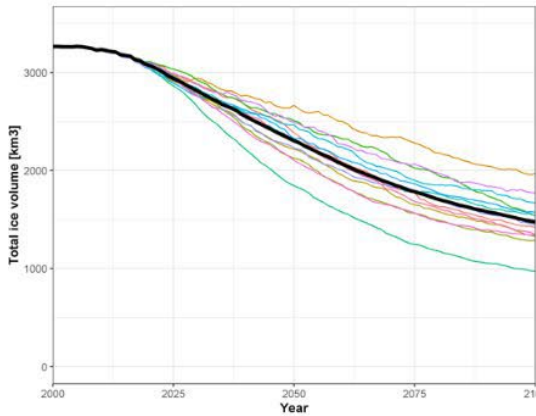
Importance of glaciers

- Glaciers contribute from 2-8 % of total runoff to Syr-Darya and Amu-Darya
- During summer the melt contribution can increase to 70 – 90%

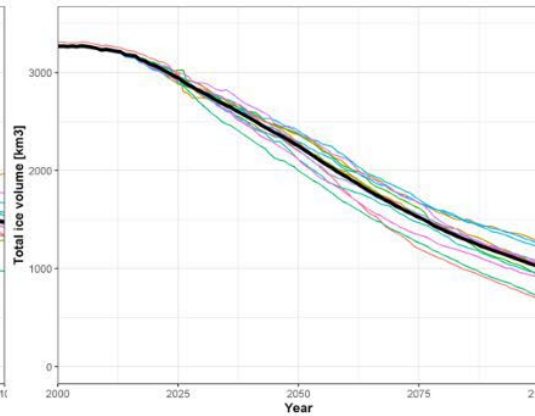


Future glacier simulations

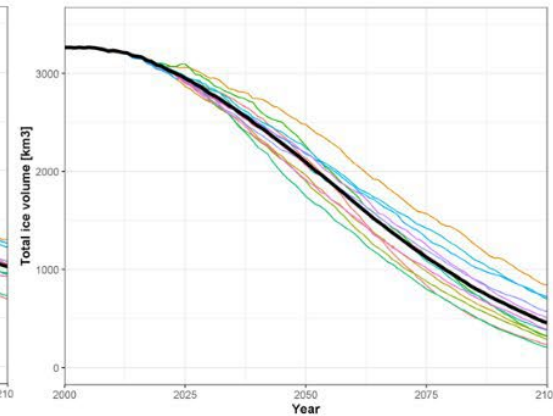
Optimistic (SSP1-2.6)



Intermediate (SSP2-4.5)



Pessimistic (SSP5-8.5)



Climate model
 BCC-CSM2-MR
 CAM5-CSM1-0
 CESM2-WACCM
 CESM2
 EC-Earth3-Veg
 EC-Earth3
 FGOALS-F3-L
 GFDL-ESM4
 INM-CM4-8
 INM-CM5-0
 MPI-ESM1-2-HR
 MRI-ESM2-0
 NorESM2-MM

Optimistic (SSP1-2.6)

Watershed	2020	2040	2060	2080	2100
	km ³	%			
Amu Darya	681	87	73	60	52
Kofarnihon	3	70	53	36	26
Panj	308	86	70	52	45
Vanchob	22	87	77	66	60
Bartang	98	89	75	60	53
Gunt	30	78	54	35	27
Wakhan	46	88	70	60	49
Pamir	19	83	62	49	38
Vakhsh	366	88	76	64	57
Khingov	63	89	73	61	55
Muksu	250	90	80	70	62
Kyzylsu	33	82	63	47	37
Syr Darya	88	66	42	24	19
Kara Darya	2	54	30	18	13
Naryn	51	63	38	20	12
Karasay	23	68	42	23	12
Zeravshan	36	82	63	52	44
Chuy	14	49	23	13	10
Kaskelen	1	44	14	8	6
Karakul	24	84	68	50	43
Issyk-Kul	20	50	25	13	11

Intermediate (SSP2-4.5)

Watershed	2020	2040	2060	2080	2100
	km ³	%			
Amu Darya	681	87	69	51	36
Kofarnihon	3	78	51	23	10
Panj	308	86	69	50	35
Vanchob	22	92	77	60	47
Bartang	98	89	74	55	41
Gunt	30	79	55	34	18
Wakhan	46	88	73	52	33
Pamir	19	85	65	42	27
Vakhsh	366	88	72	56	41
Khingov	63	87	72	54	40
Muksu	250	90	78	63	48
Kyzylsu	33	84	63	40	26
Syr Darya	88	70	37	17	7
Kara Darya	2	57	25	8	3
Naryn	51	65	31	11	3
Karasay	23	69	35	12	3
Zeravshan	36	83	60	40	25
Chuy	14	53	19	6	2
Kaskelen	1	42	10	4	1
Karakul	24	84	64	43	27
Issyk-Kul	20	53	20	7	3

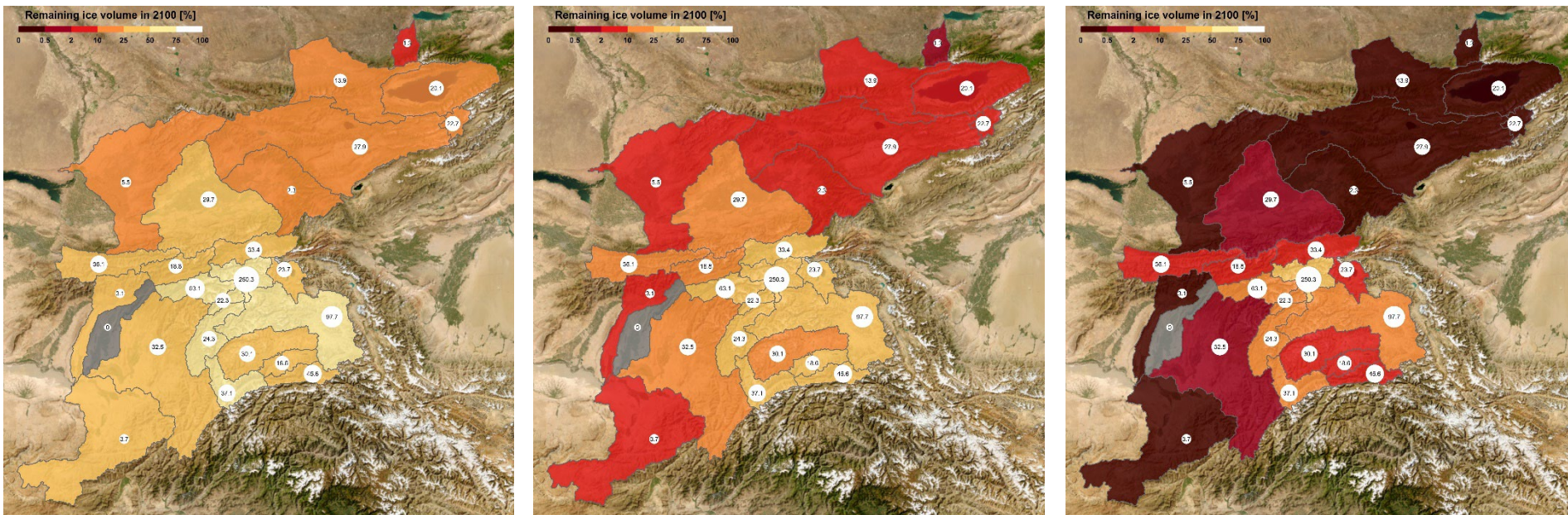
Pessimistic (SSP5-8.5)

Watershed	2020	2040	2060	2080	2100
	km ³	%			
Amu Darya	681	85	60	37	21
Kofarnihon	3	71	27	6	0
Panj	308	83	54	31	14
Vanchob	22	89	67	44	24
Bartang	98	86	61	39	20
Gunt	30	74	40	14	2
Wakhan	46	84	57	32	9
Pamir	19	80	51	28	8
Vakhsh	366	87	66	43	26
Khingov	63	83	61	36	16
Muksu	250	89	71	50	33
Kyzylsu	33	80	49	22	8
Syr Darya	88	62	27	5	1
Kara Darya	2	48	16	2	0
Naryn	51	56	23	3	0
Karasay	23	60	26	3	0
Zeravshan	36	81	50	24	6
Chuy	14	44	12	1	0
Kaskelen	1	35	5	1	0
Karakul	24	81	52	25	7
Issyk-Kul	20	44	12	2	0

- Ice volume loss ranging from 58% (low-emission scenario) to 85% (high-emission scenario) of the total ice volume in 2020 by 2100

Future glacier scenarios

Ice volume change by 2100 relative to current ice volume (2020)

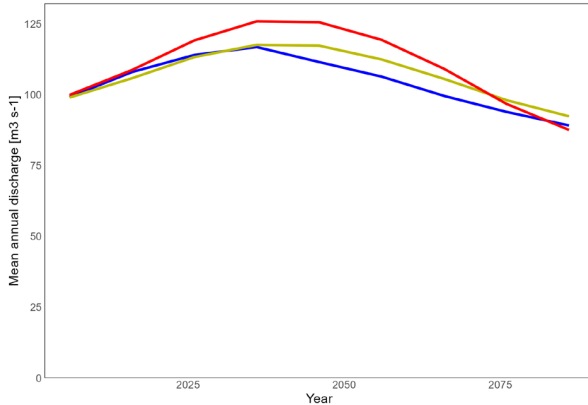


Changes in ice volume per catchment for optimistic, intermediate and pessimistic scenarios

At least 25% of ice is lost even under the most favorable scenario !! Up to complete disappearance of the glaciers along the western margin of the Pamir and large parts of the Tien Shan

Glacier melt loss in Syr-Darya and Amu-Darya

Catchment: Syr Darya at Chardara reservoir



Optimistic (SSP1-2.6)

Watershed	Discharge: 1991-2020	Change in discharge: 2001-2030	Change in discharge: 2031-2060	Change in discharge: 2071-2100
		(m³ s⁻¹)		
Amu Darya	318	28	74	28
Bartang	41	4	11	4
Chuv	26	1	-1	-5
Gunt	19	2	5	0
Issykkul	30	2	0	-7
Karadarya	4	0	0	0
Karakul	8	1	4	2
Karasav	14	1	4	-2
Kaskelen	3	0	0	-1
Khingov	47	4	10	4
Kofarnihon	7	0	1	0
Kyzylsu	20	2	6	2
Muksu	79	8	24	13
Naryn	45	5	8	-5
Pamir	8	1	2	0
Pani	134	13	30	8
Syr Darya	99	9	12	16
Vakhsh	173	16	44	20
Vanchob	17	1	3	15
Wakhan	5	0	1	1
Zeravshan	37	3	5	0

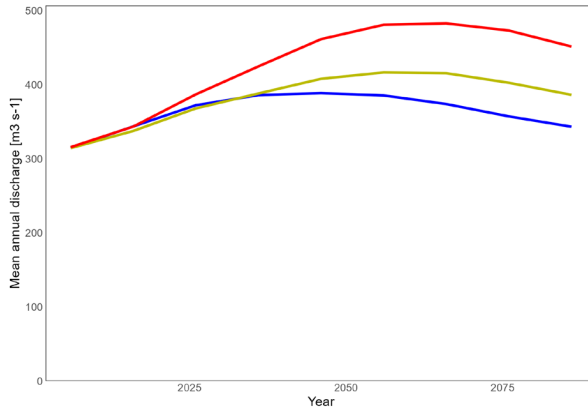
Intermediate (SSP2-4.5)

Watershed	Discharge: 1991-2020	Change in discharge: 2001-2030	Change in discharge: 2031-2060	Change in discharge: 2071-2100
		(m³ s⁻¹)		
Amu Darya	314	23	94	72
Bartang	41	3	15	11
Chuv	26	1	0	-5
Gunt	18	2	6	2
Issykkul	30	2	1	-6
Karadarya	4	0	1	0
Karakul	8	1	5	4
Karasav	14	1	5	-1
Kaskelen	3	0	0	-1
Khingov	47	3	13	11
Kofarnihon	7	0	1	0
Kyzylsu	20	2	8	5
Muksu	79	6	27	28
Naryn	45	4	10	-4
Pamir	8	1	3	1
Pani	134	10	41	26
Syr Darya	99	7	18	7
Vakhsh	173	13	52	46
Vanchob	17	1	4	4
Wakhan	5	0	1	0
Zeravshan	37	2	7	4

Pessimistic (SSP5-8.5)

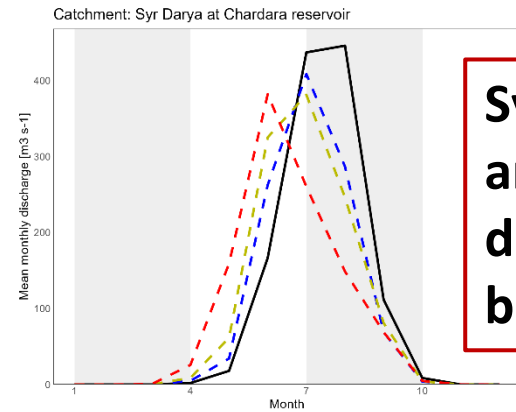
Watershed	Discharge: 1991-2020	Change in discharge: 2001-2030	Change in discharge: 2031-2060	Change in discharge: 2061-2090
		(m³ s⁻¹)		
Amu Darya	318	28	146	136
Bartang	41	4	23	22
Chuv	26	1	1	-8
Gunt	18	2	9	4
Issykkul	30	2	2	-6
Karadarya	4	0	1	0
Karakul	8	1	8	5
Karasav	14	1	7	-3
Kaskelen	3	0	0	-1
Khingov	47	3	18	18
Kofarnihon	7	0	1	0
Kyzylsu	21	2	11	6
Muksu	79	7	45	64
Naryn	45	4	14	-7
Pamir	8	1	4	3
Pani	134	13	61	48
Syr Darya	100	9	26	-12
Vakhsh	174	14	82	89
Vanchob	17	1	6	7
Wakhan	5	0	2	0
Zeravshan	37	3	11	5

Catchment: Amu Darya downstream of Kofarnihon inflow

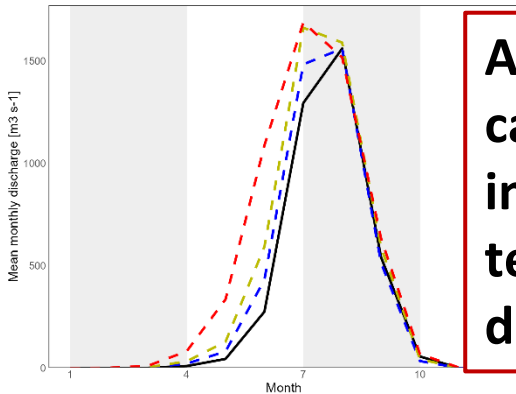


- Syr Darya will reach peak flow by middle of century followed by significant reduction in annual glacier meltwater inflow by the end of the century.
- Amu Darya basin, is projected to experience an increase in meltwater contribution by the end of the century.

Seasonal impact of disappearing ice volume on water resources during the hot and dry summer months



Syr Darya: Most drastic changes are expected in August and September. Peak discharge will shift to early spring due to the dominance of snow melt. A strong deficit is to be expected for Syr Darya.



Amu Darya: Due to the strong glaciation in the catchment, melt rates will still be increasing with increasing air temperatures. With increasing air temperature, melt season will be prolonged and peak discharge will shift to earlier in the season.

Conclusions

1. **The mountain snow reservoir is shrinking.** Peak SWE in the 2000–3000 m melt zone falls by **up to 36% (Syr Darya) and 51% (Amu Darya)** by 2100 under high emissions.
2. **The melt season is moving earlier.** Half-melt arrives ~2 weeks sooner, runoff centroid ~3 weeks sooner.
3. **Summer water supply will be squeezed.** Even where annual runoff holds up (Syr Darya), the seasonal shift moves water out of phase with the June–August irrigation peak. Amu Darya faces a double hit: **less water, and earlier.**
4. **Low and mid elevations lose the most.** Below 2000 m, seasonal snow effectively disappears. Syr Darya is particularly exposed because it lacks the high-altitude buffer (>4000 m) that helps offset losses in Amu Darya.
5. At least **25% of ice** is lost even under the most favorable scenario !! Up to complete disappearance of the glaciers along the **western margin of the Pamir and large parts of the Tien Shan**
6. Most drastic changes in glacier melt contribution are expected in August and September in **Syr Darya**. A strong summer deficit is to be expected. Glacier **increased melt rates and prolonged melt season** are expected in **Amu Darya**.



Schweizerische Eidgenossenschaft
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Direktion für Entwicklung
und Zusammenarbeit DEZA

Thank you!



**CRYOSPHERE
PROJECT** | in Central Asia

CROMO-ADAPT

PAMIR

SWISS POLAR INSTITUTE
FLAGSHIP INITIATIVE



CICADA 
Cryospheric Climate Services for Improved Adaptation

CATCOS 
Capacity Building and Twinning for Climate Observing Systems

