Studying scale effects in streamflow response in glacierized Baksan river catchment in the North Caucasus using natural stable isotopes

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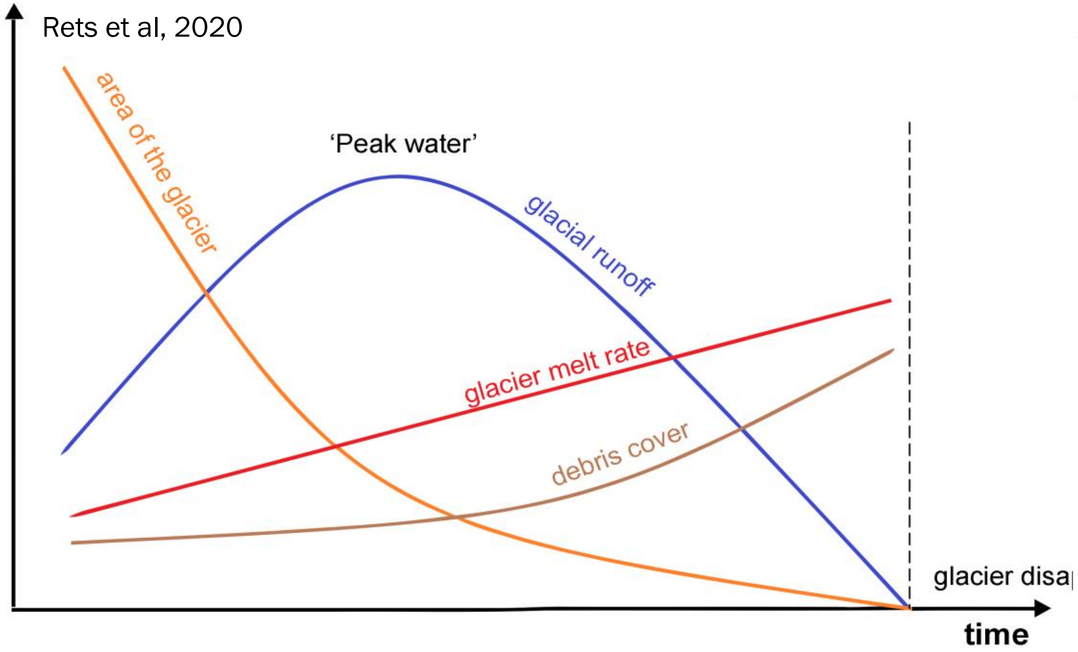
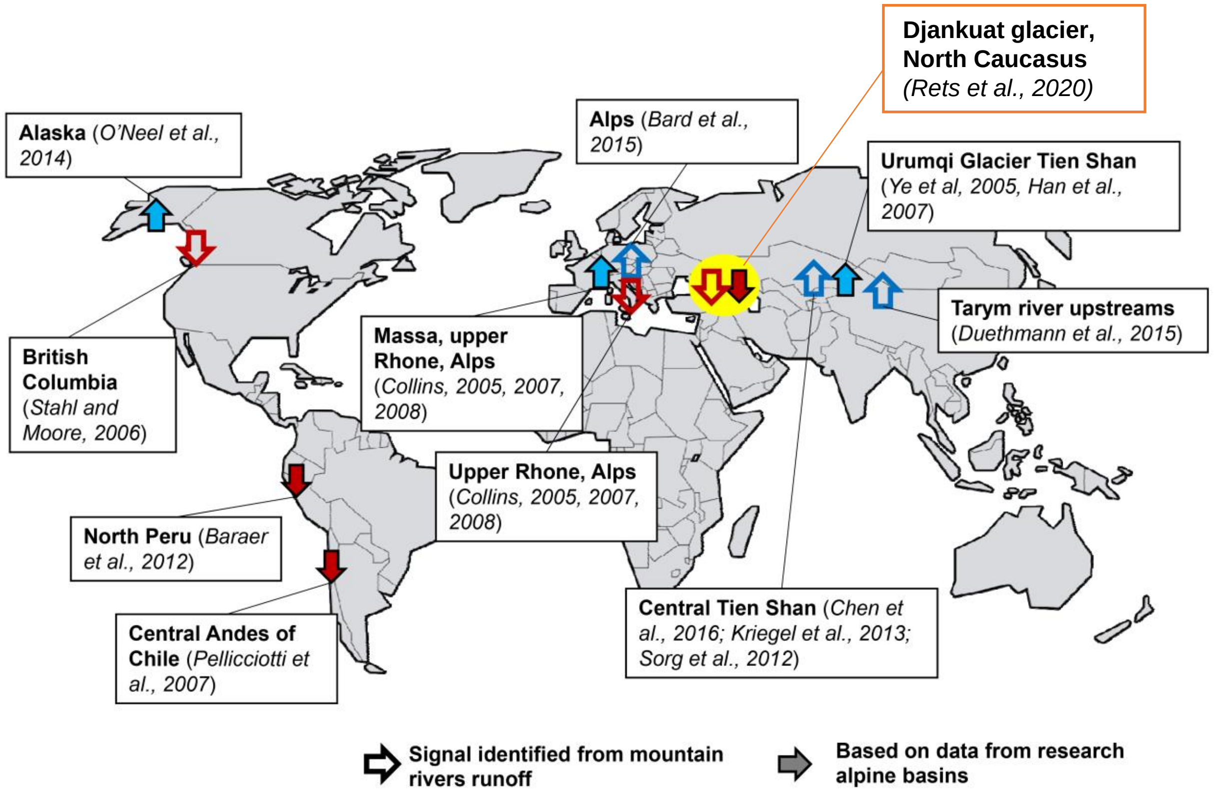
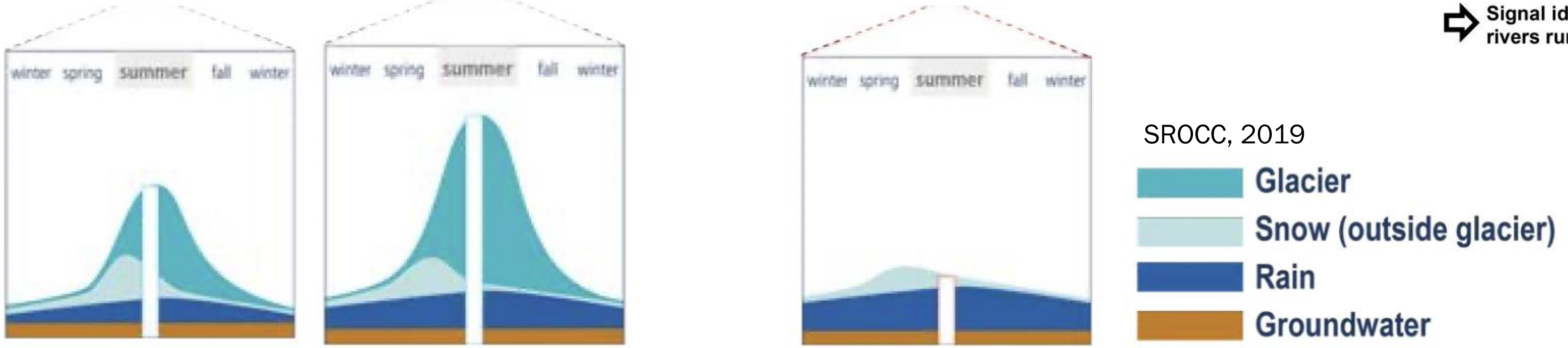
2 Hydrological consequences of deglaciation

Rets et al, 2020



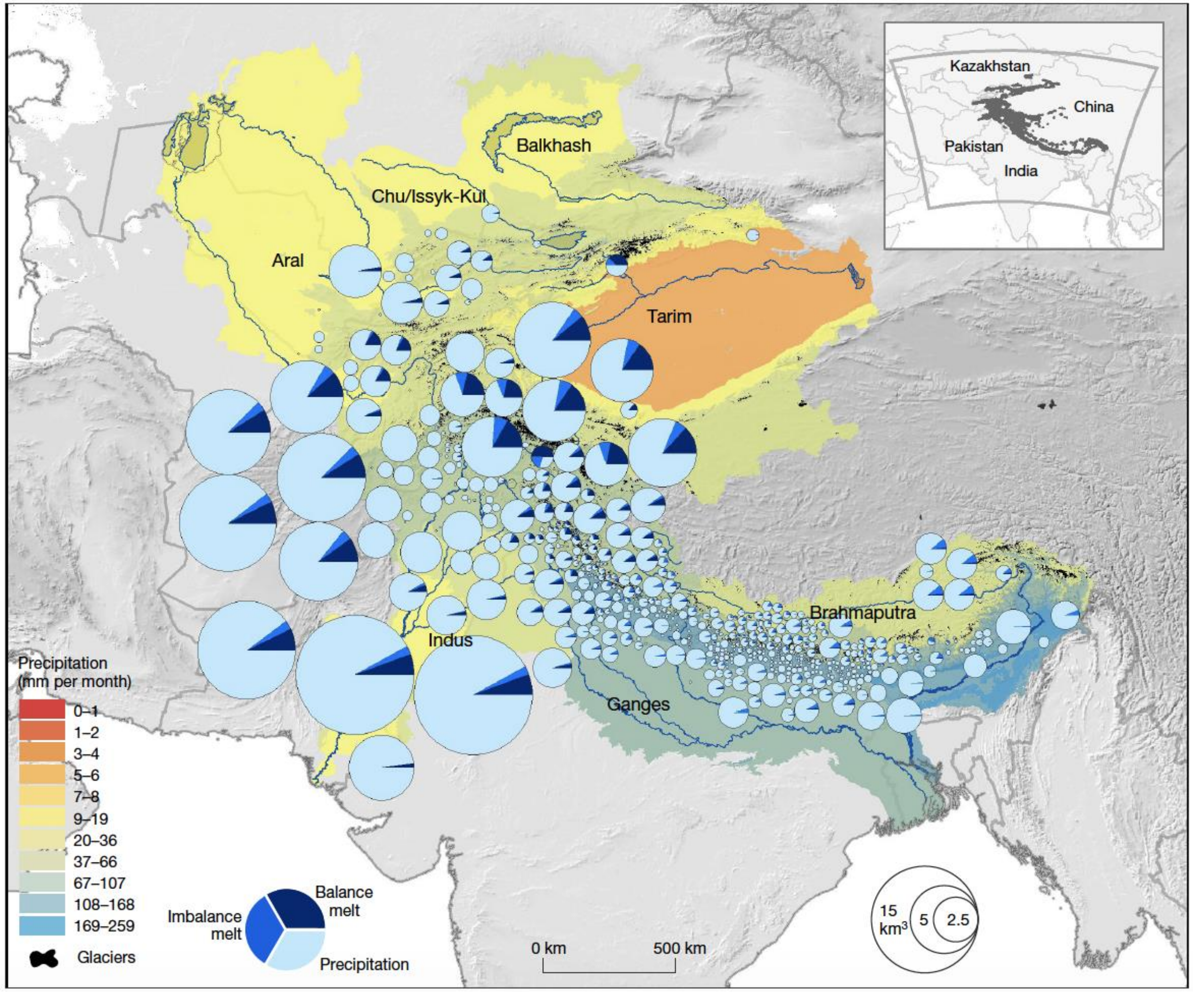


SROCC, 2019

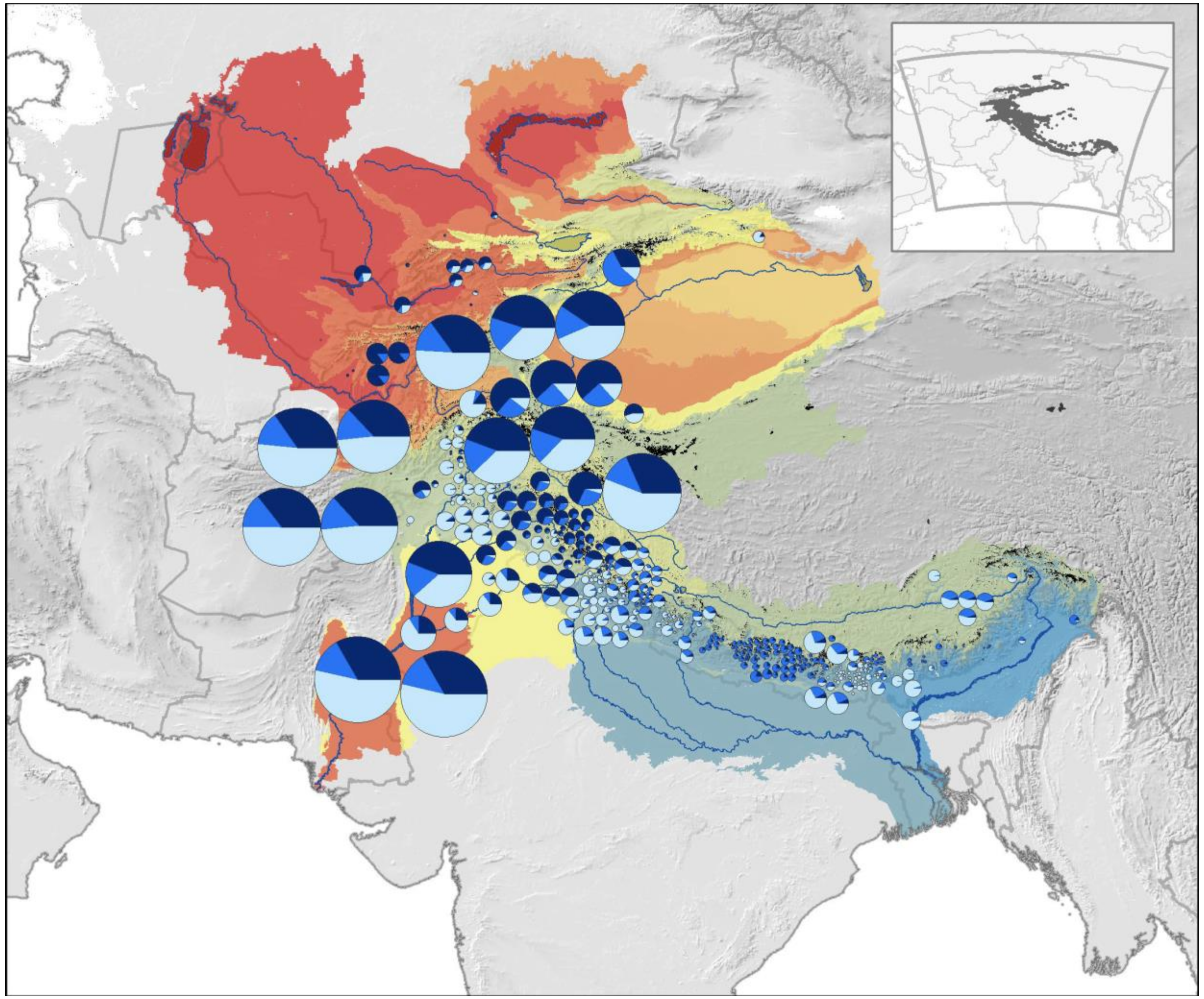


3 When glacial runoff is important

- Precipitation and glacial melt inputs in an **average year**

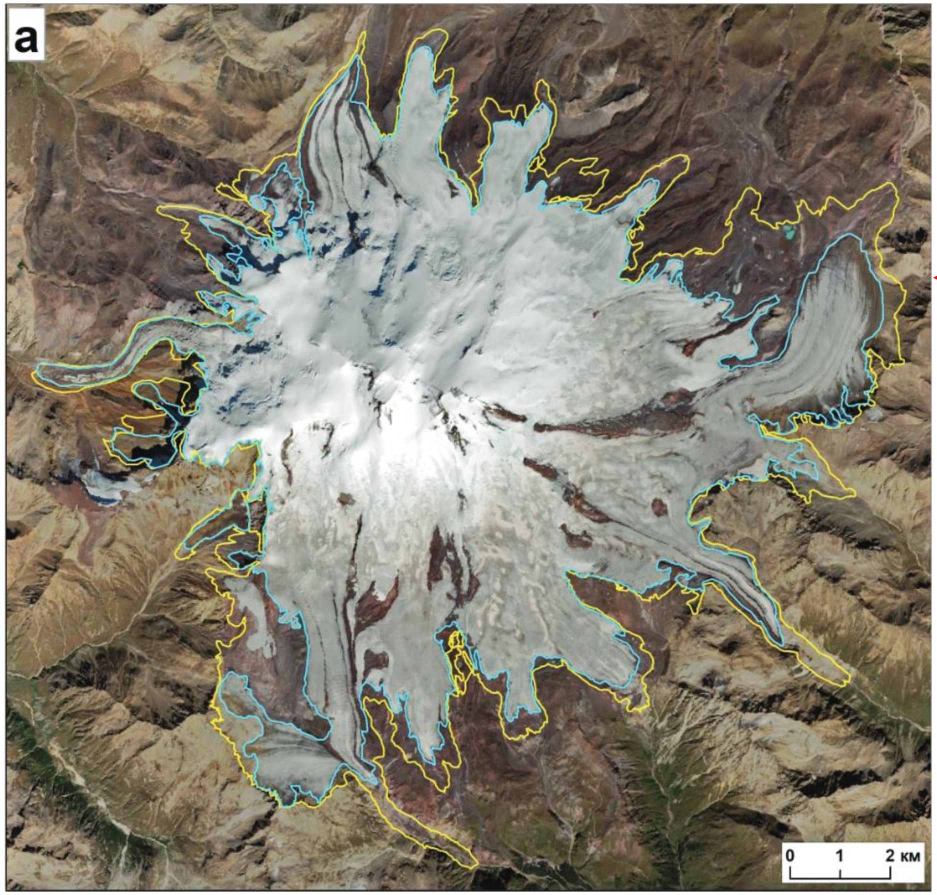


- Precipitation and glacial melt inputs in a **drought year**

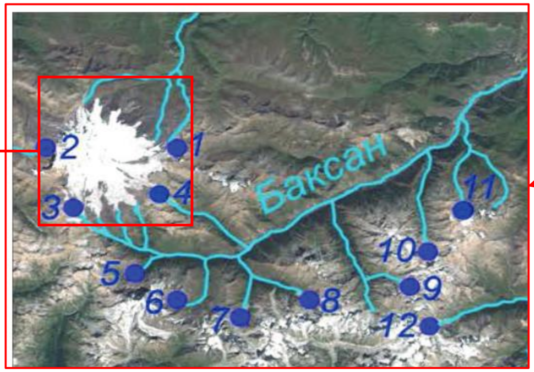


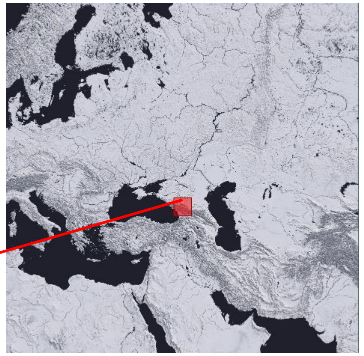
Pritchard, 2019

4 Deglaciation in the Baksan river basin (North Caucasus)

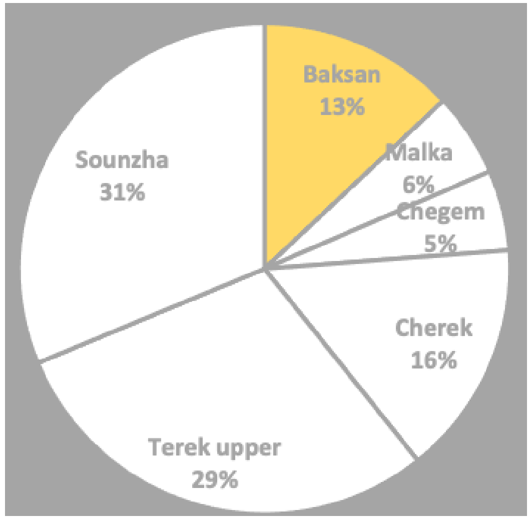


Elbrus mountain glacier outlines in 1957 and 2020 (Bekkiev et al, 2021)





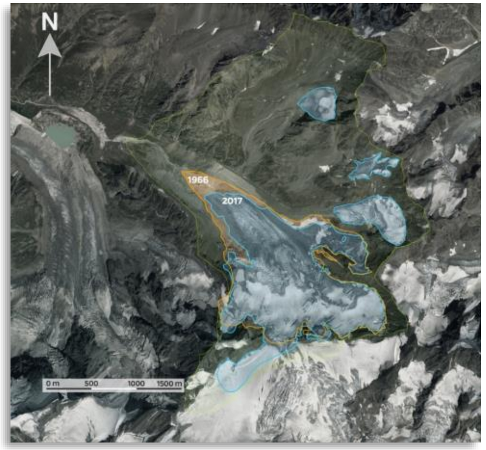
Relative contribution of the Baksan river in Zajukovo reach to the Terek river basin water resources

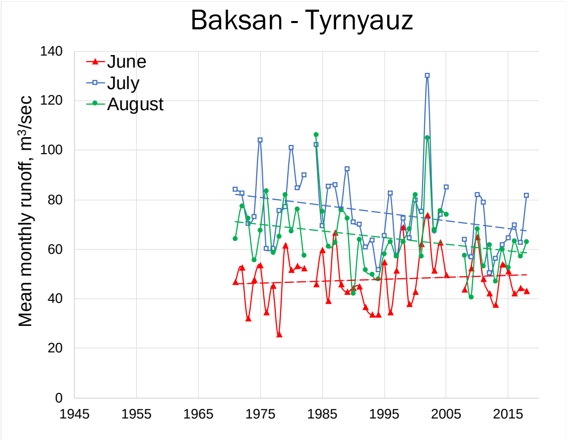


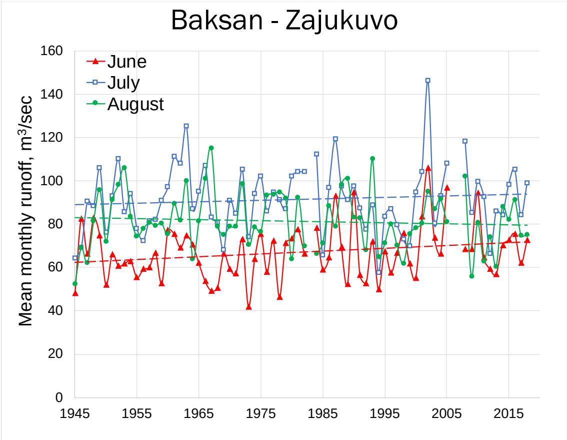
Changes in area and length of selected glaciers in the **Baksan** river basin (Bekkiev et al, 2021)

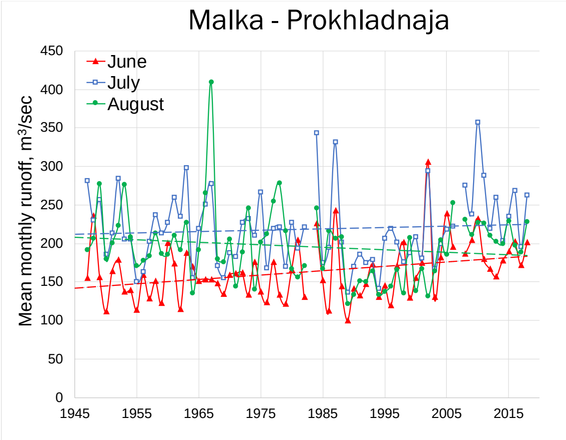
#	Area, km²	Decrease in area, km² (%) from 1957 to 2020	Decrease in length, m
3	19.6 (21.03)	6.35±0.20 (30.2-32.4)	2580
4	10.5 (11.0)	0.79±0.05 (7.2-7.4)	1475
5	2.7	0.03±0.002 (1.0)	100
6	2.8	0.22±0.02 (7.9)	260
7	5.6	1.24±0.04 (22.1) **1960-2020**	1790
8	3.4	0.37±0.02 (10.9)	440
9	1.9	0.44±0.02 (23.0)	650
10	2.5	0.59±0.04 (23.7) **1962-2020**	520
11	3.05[3]	1.23±0.08 (40.3)	640

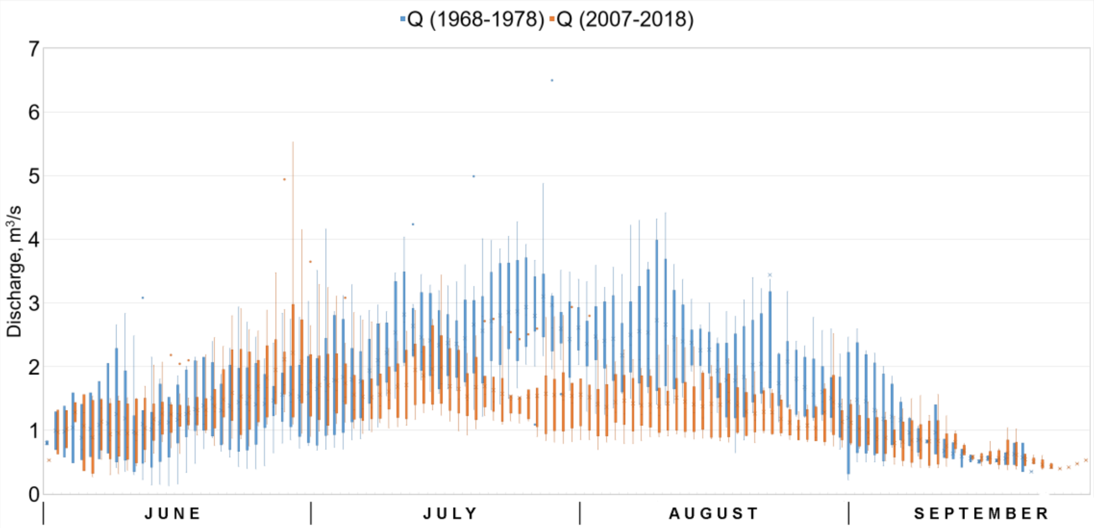
5 Past 'peak water' in central Northern Caucasus (Rets et al, 2020)











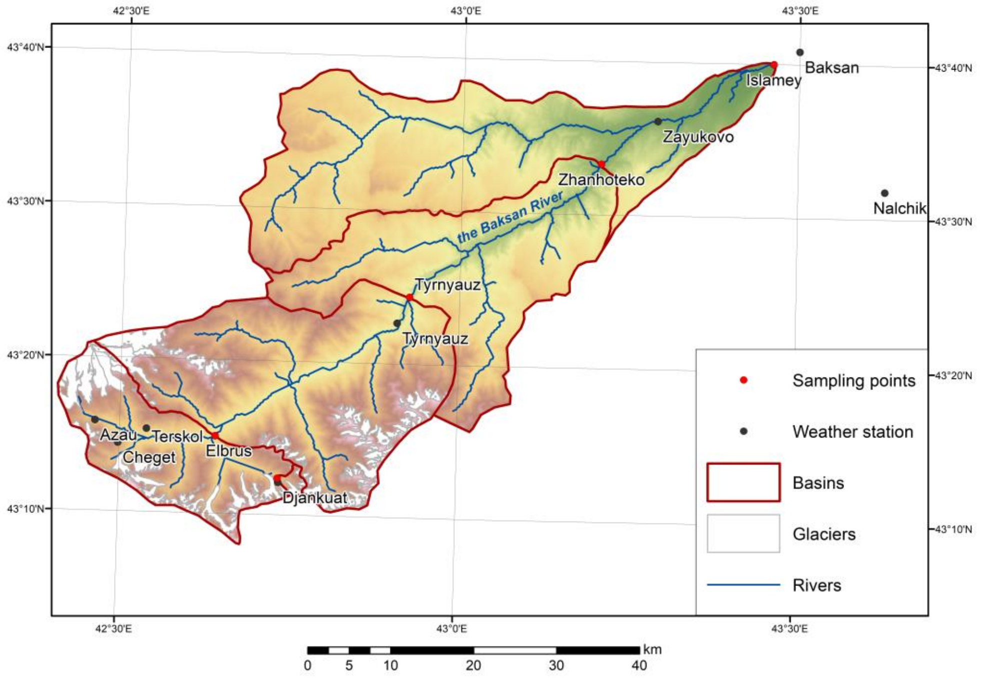
- Box plot of daily discharges measured during two periods of observation (1968–1978 and 2007–2017) at the Djankuat research basin gauging station (headwaters of the Baksan river)

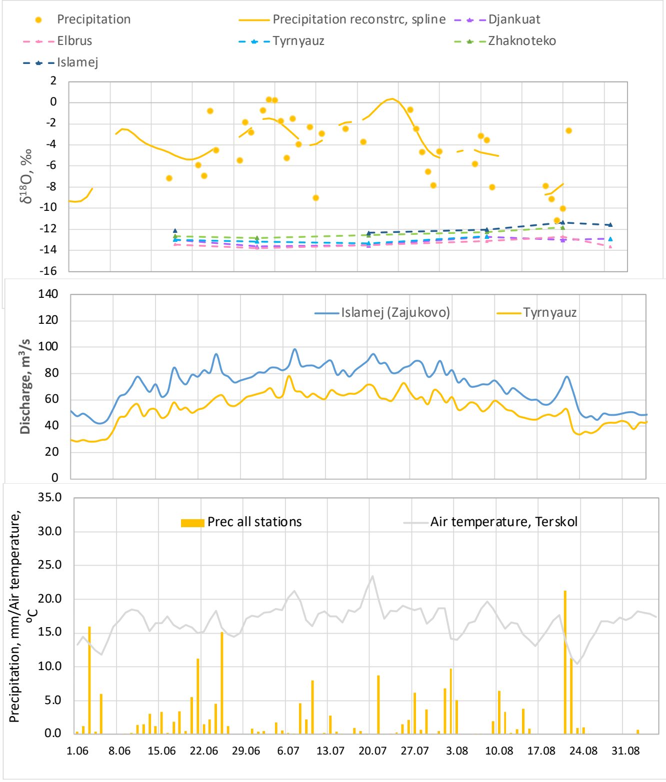
№	River - Gauge	Label	Latitudinal position	Years	Watershed area, km2	Mean elevation of the watershed, m	Glacierization ratio, %	Change in mean monthly runoff, % per 10 y			Change in Aug to Jun runoff ratio, % per 10 y	Change in Qmax annual, % per 10 y	Change in Date of Qmax between 1945-1985 and 1986-2018, days
								June	July	Aug			
Highly glacierized watersheds													
1	Terek - Vladikavkaz	Ter-Vla	East	73	1490	2540	3.82	1.5	-0.7	**-3.0**	**-4.3**	-4.1	-4
2	Terek - Kotliarevskaja	Ter-Ko	East	73	8920	1800	3.27	1.7	-0.7	-1.0	-2.6	1.3	-12
3	Tseja - Buron	Tse-Bu	East	66	100	2820	25.1	0.3	-2.0	-2.9	-1.5	**-0.6**	2
4	Urukh - Khaznidon	Uru-Kh	East	49	1150	2360	9.58	3.8	1.7	0.6	-2.5	1.1	-8
5	Cherek Balkarsky - Babugent	Che-Ba	Center	60	695	2590	23.5	1.4	-0.1	-0.6	-1.5	-1.0	-10
6	Baksan - Tyrnyauz	Bak-Ty	Center	45	838	2990	27.2	1.7	**-4.2**	**-4.1**	-7.0	**-4.4**	0
7	Baksan - Zajukovo	Bak-Za	Center	71	2100	2360	10.9	1.9	0.7	-0.6	**-2.5**	0.9	-6
8	Malka - Kamennomostskoje	Mal-Ka	Center	69	1540	2000	5.38	**5.4**	2.9	**2.4**	-2.6	-0.5	4
9	Malka - Prokhladnaja	Mal-Pr	Center	70	9820	1900	7.34	**3.4**	0.8	-1.7	**-5.0**	-0.1	-12
10	Ullu-Kam - Khurzuk	Ull-Ka	Center	59	594	2810	14.1	1.5	-1.2	**-2.8**	-4.7	-1.2	-6
11	Teberda - Teberda	Teb-Te	Center	60	504	2580	16.4	**-2.2**	**-4.3**	**-4.2**	-2.4	-1.0	-1
12	Kuban - Kosta Khetagurova	Kub-Ko	Center	60	3800	2220	5.40	1.6	-0.8	-2.2	**-3.2**	**10.1**	-10
13	Kuban - Armavir	Kub-Ar	Center	68	16900	1220	2.70	-0.2	-2.0	**-6.3**	**-6.0**	-0.5	-4
14	Marukha - Marukha	Mar-Ma	West	64	301	2190	1.21	3.4	1.7	2.2	-0.1	5.8	-2
15	Aksaut - Khasaut-Grecheskoye	Aks-Kh	West	64	530	2480	6.02	1.1	2.0	-1.0	-1.5	**7.0**	-2
16	Bolshoj Zelenchuk - Arkhyz	Bze-Ar	West	70	513	2170	3.04	**7.8**	**5.4**	**3.6**	**-4.1**	**11.0**	2
17	Bolshoj Zelenchuk - Zelenchukskaja	Bze-Ze	West	72	802	1700	4.20	0.6	-1.1	**-2.8**	**-3.3**	**7.1**	7

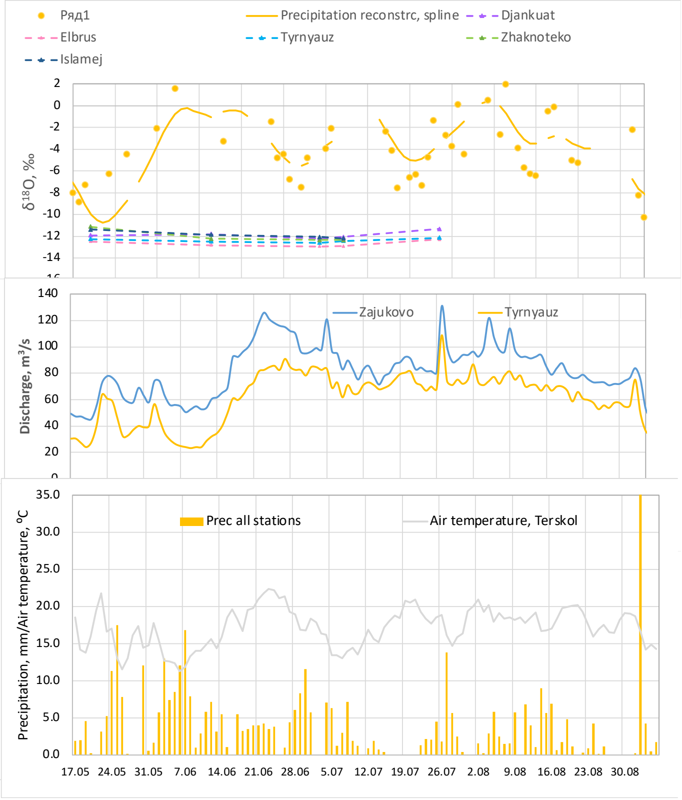
6 Study sites and data

- River water sampling on stable isotopes in 5 gauges along the Baksan river:
 6 times in 2020 and 5 in 2021
- Event-based precipitation sampling on stable isotopes in Azau (2019-2021) and Djankuat (2020)
- Precipitation amount on 8 meteorological stations
- Archive hydrometeorological and isotopic data collected in the Djankuat research basin (2013-2017) (Rets et al, 2019)
- Elbrus deep ice core isotopic analisys data (Mikhalenko et al., 2015)

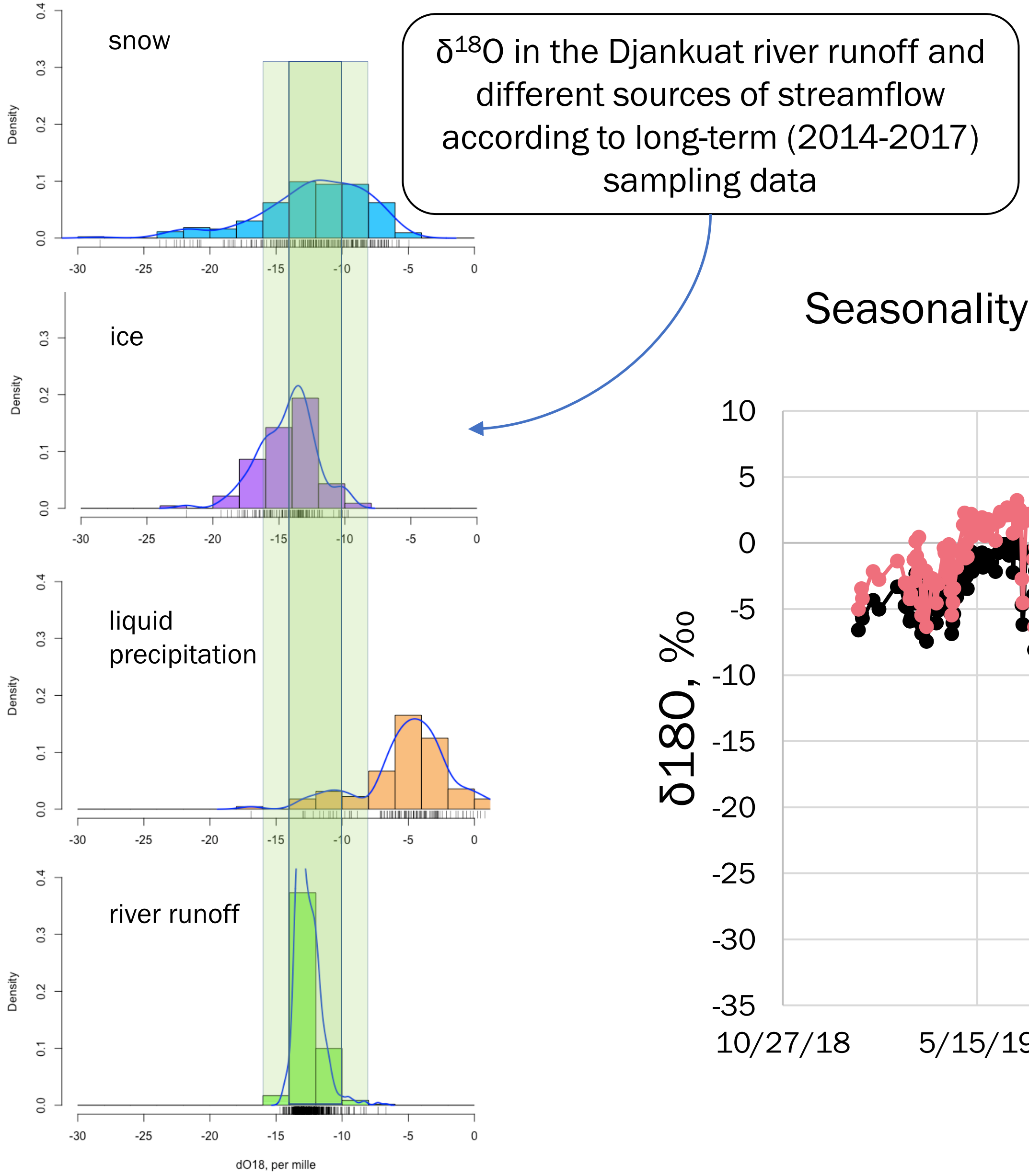
#	River	Gauge	Basin area, km2	Glaciation rate, %
1	Djankuat	Djankuat	8.7	30
2	Baksan	Elbrus	376	27
3		Tyrnyauz	1209	16
4		Zhankhoteko	1794	11
5		Islamej	2941	7

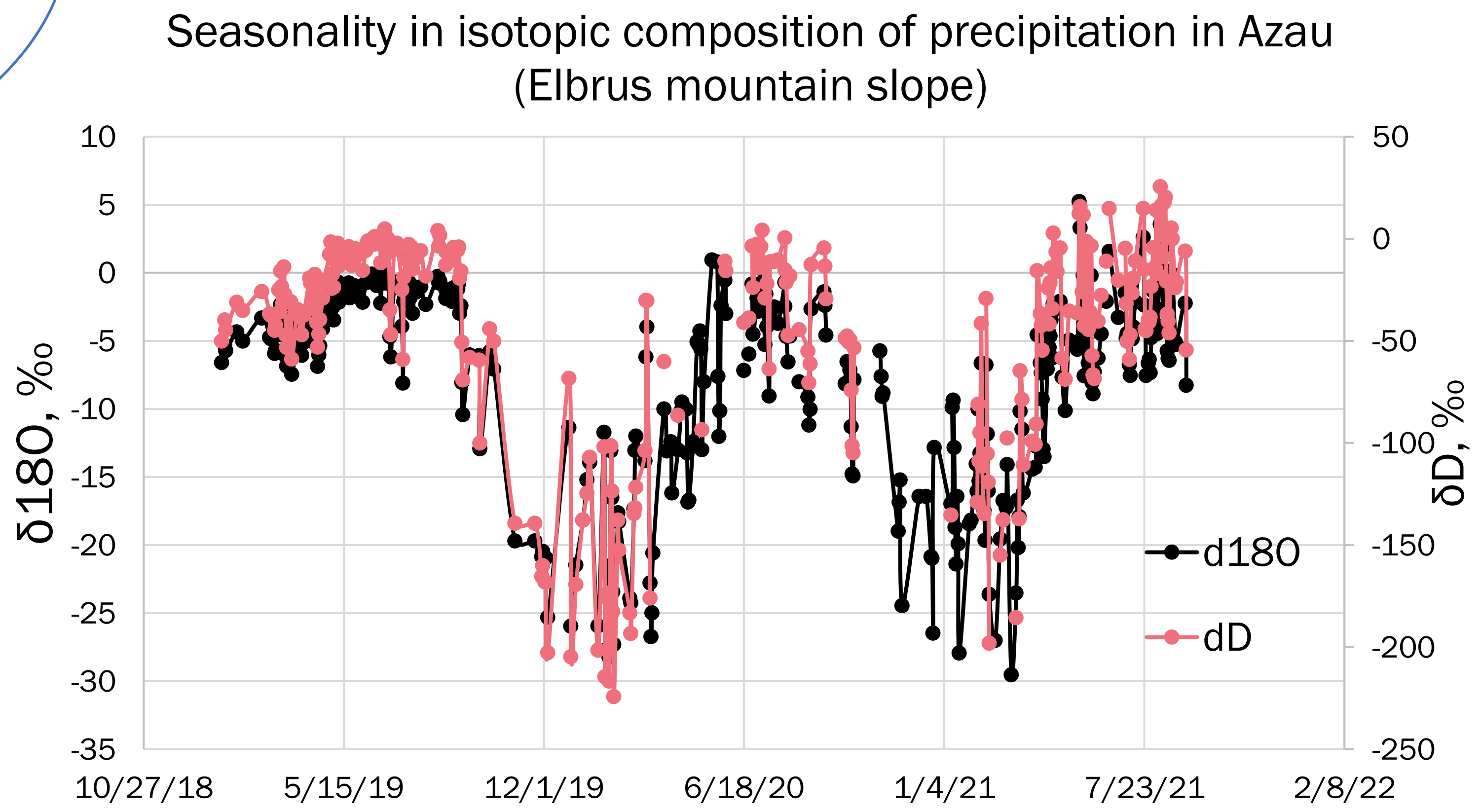






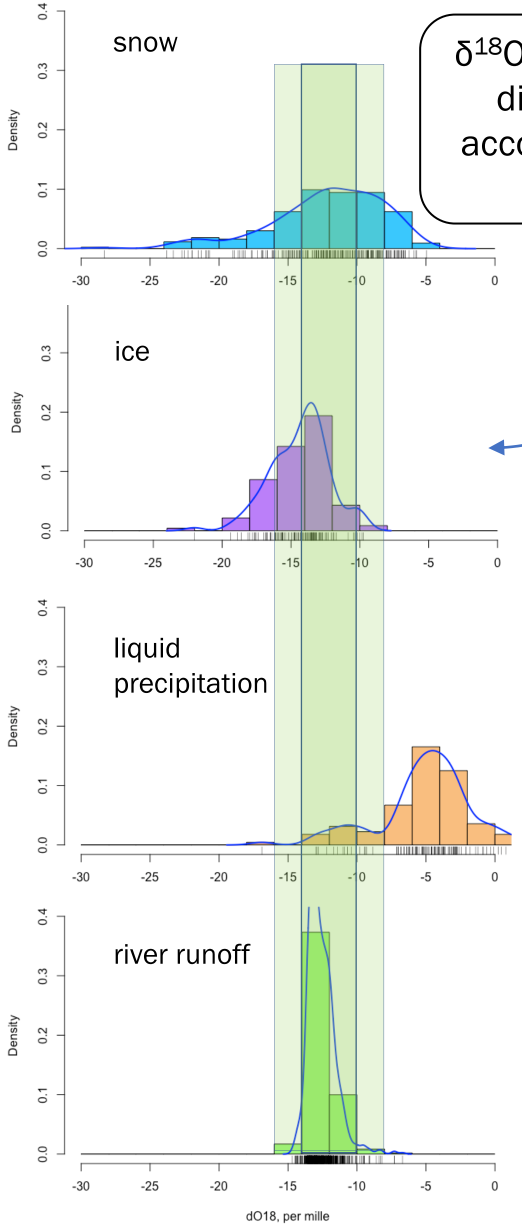
7 Natural stable isotopes as tracers of runoff sources (1/2)



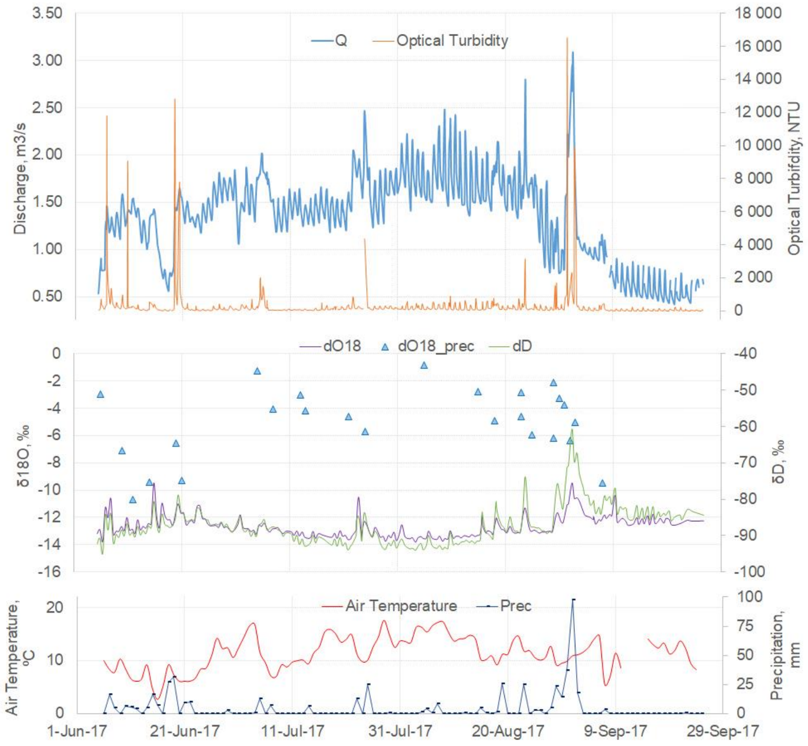


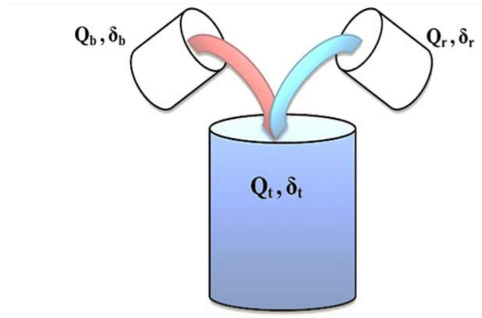
8 Natural stable isotopes as tracers of runoff sources (2/2)

δ18O in the Djankuat river runoff and different sources of streamflow according to long-term (2014-2017) sampling data



Dynamics of the Djankuat river runoff and δ18O in river runoff and precipitation

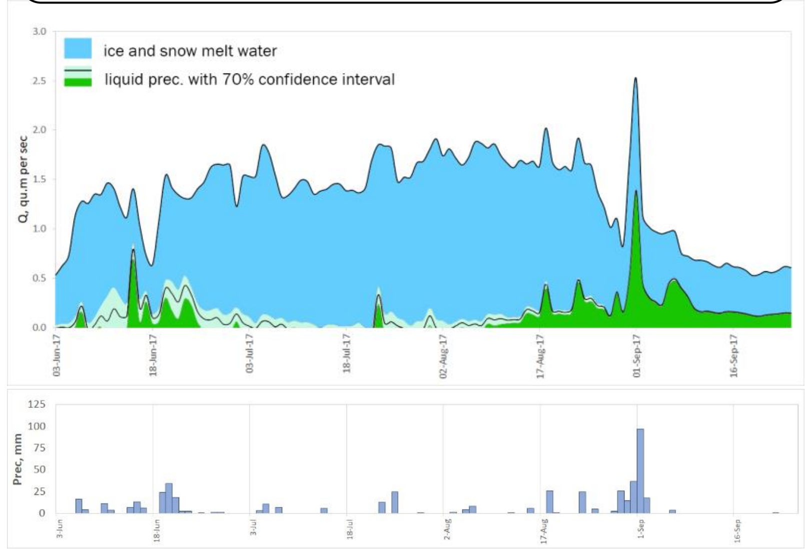




$$Q_t = Q_b + Q_r$$
$$Q_t \delta_t = Q_b \delta_b + Q_r \delta_r$$
$$Q_r = Q_t \frac{\delta t - \delta b}{\delta r - \delta b}$$

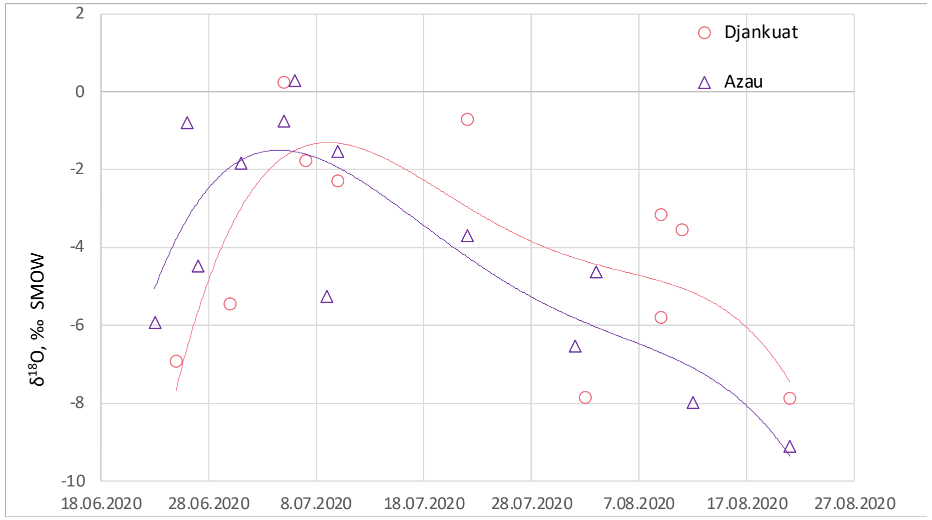
Mixing model

Two-component separation of Djankuat river hydrograph in 2017

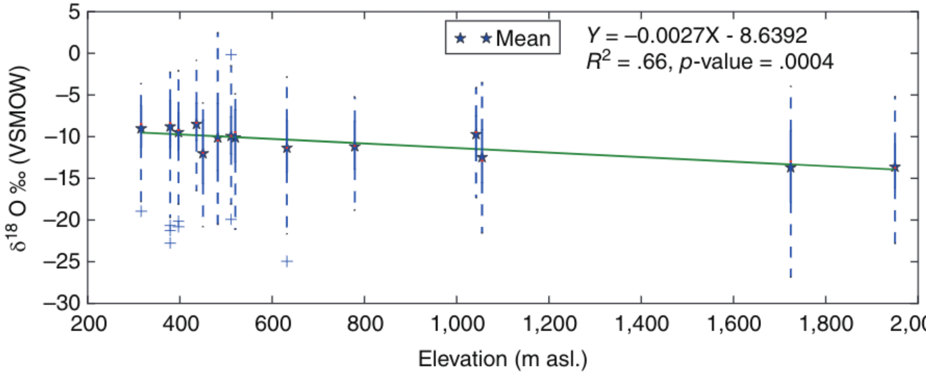


9 Estimating isotopic signature of rainfall

- Data on event-based precipitation sampling in Azau (2020-2021) and Djankuat (2020) meteorological stations was used
- 4-day weighted precipitation amount average was used for each day of river flow sampling
- Representative of each watershed meteorological station was used to define the precipitation amount for the previous step



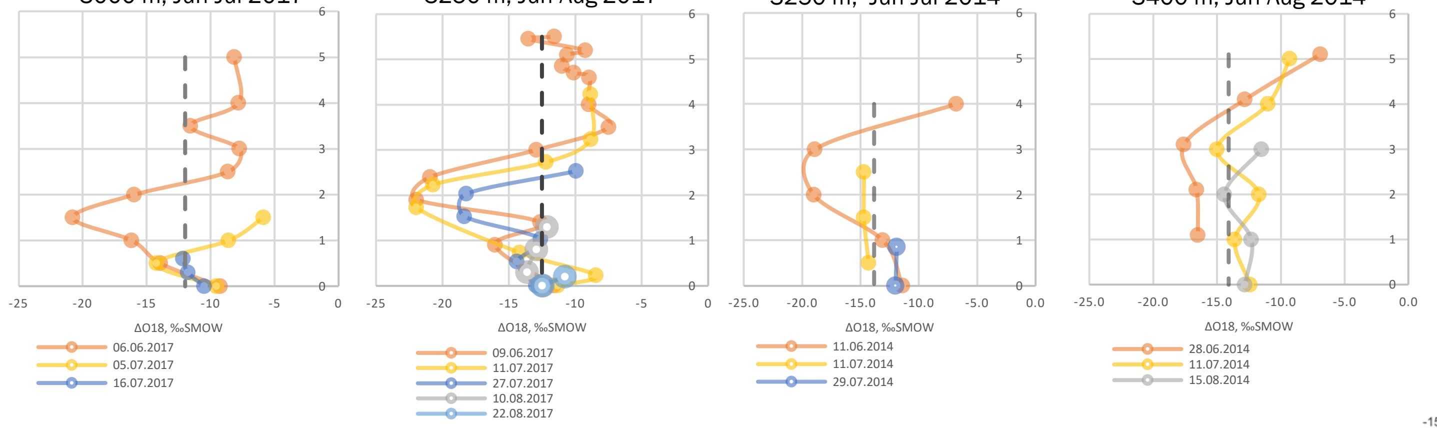
Spatial heterogeneity of dO18 in precipitation over the study area

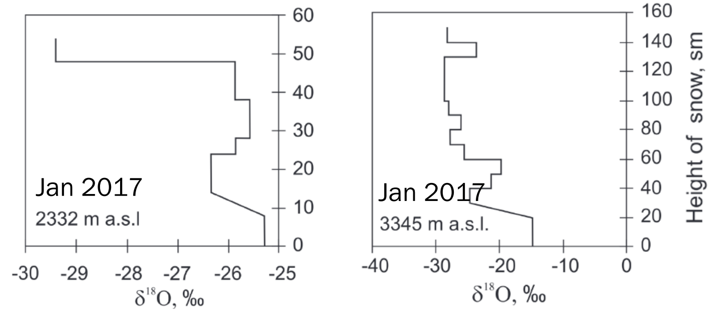


Variation of δ18O in precipitation samples with elevation on network of gauging stations in Switzerland (data from 1966 to 2014).
Snowfall is widespread during winter at elevations >800 m asl.(Marty, 2008)

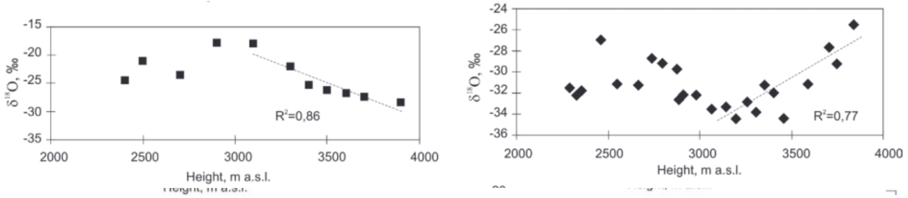
10 Estimating isotopic signature of melt component: **1. SNOW**

Distribution of $\delta^{18}O$ in snowpits on the **Djankuat glacier**

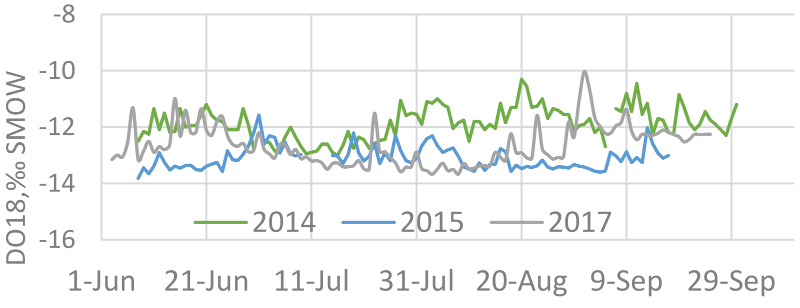




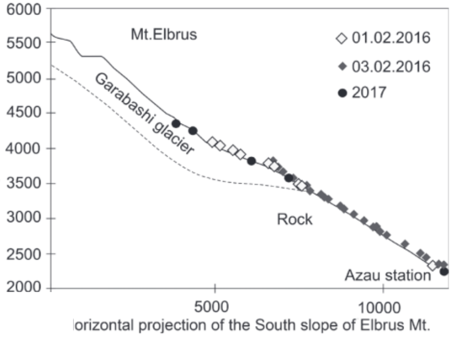
Distribution of $\delta^{18}O$ in snowpits on the southern **Elbrus slope** in January 2017 (Vasil'chuk et al., 2020)



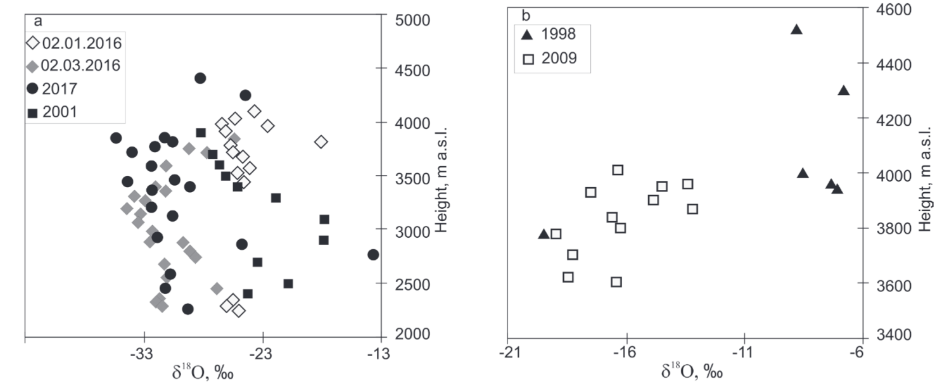
. The altitudinal effect on $\delta^{18}O$, $\delta^{2}H$ and d_{exc} for fresh snow in 8 February 2001 and 3 February 2016



Dynamics of O18 content in Djankuat river runoff in 2014-2017

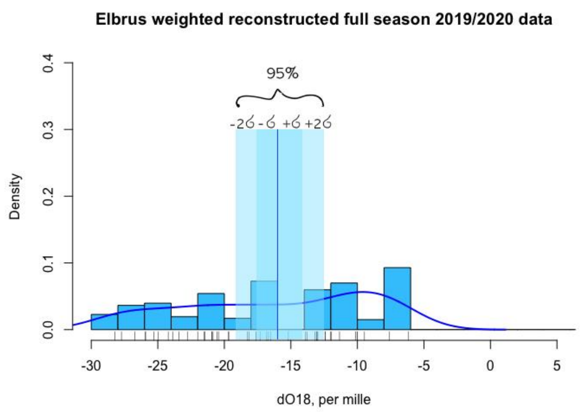


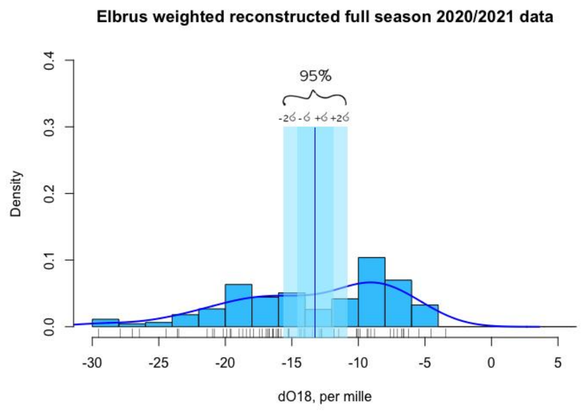
Sampling profile on the southern slope of Elbrus



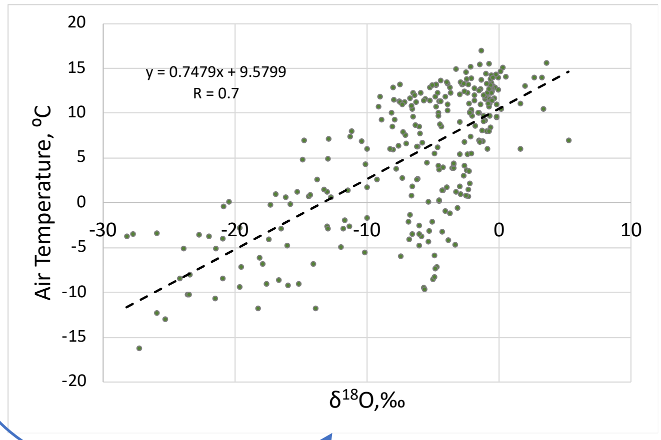
. The $\delta^{18}O$ values in snow cover of Elbrus Mountain in winter (a) and summer season (b)

11 Estimating isotopic signature of melt component: **1. SNOW**

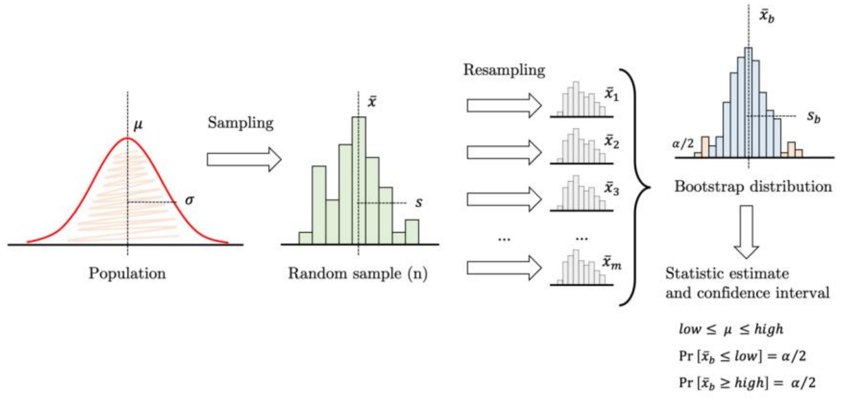




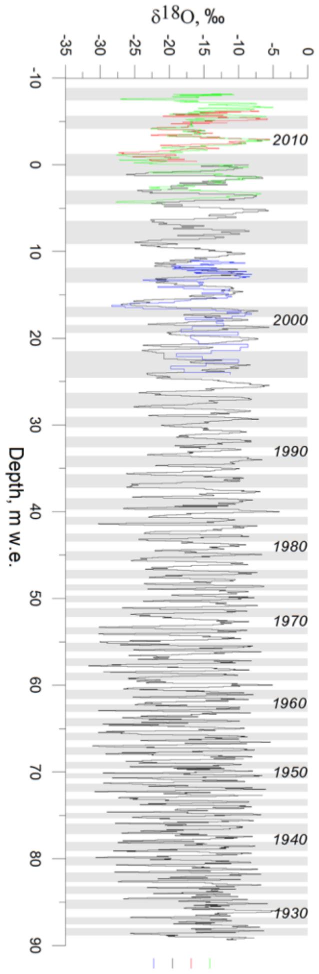
- Data on solid precipitation event-based sampling on Azau meteorological station were used
- Missing values were reconstructed using the dependency between $\delta^{18}O$ and mean daily air temperature
- The isotopic signatures of each snow event very weighted according to the precipitation amount to estimate the mean value of $\delta^{18}O$ in the snowpack
- A bootstrapping procedure was used to determine confidence interval for the estimation of the mean value of $\delta^{18}O$. It was set as +/- σ (≈ 70% confidence inteval)



Bootstrapping procedure

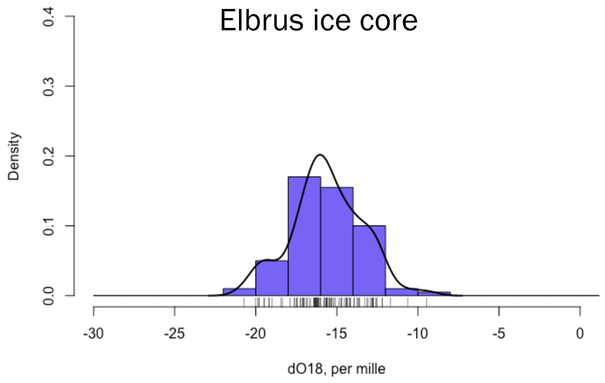


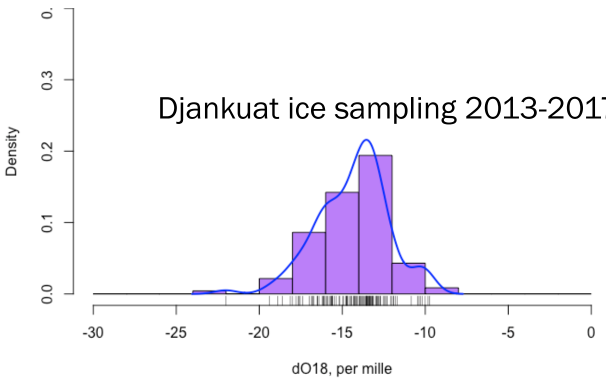
12 Estimating melt component isotopic signal: **2. ICE**



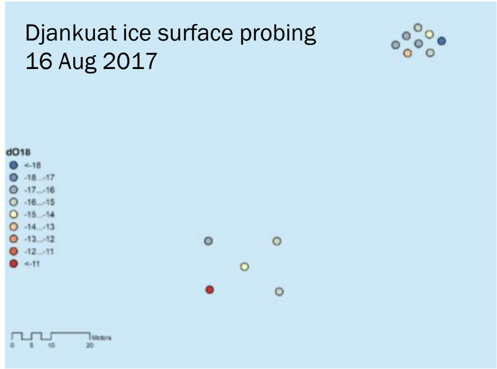
δ18O profiles of the Elbrus ice core (Mikhalenko et al. 2015)

- Data on δ18O profiles in a deep ice core from the Elbrus western plateau (Mikhalenko et al., 2015) was used to estimate ice isotopic signal in the Baksan river basin
- Data on ice sampling for isotopic composition for 2013-2017 on the Djankuat glacier was used to estimate ice isotopic signal in the Djankuat river basin
- A bootstrapping procedure was used to determine confidence interval for the estimation of the mean value of $\delta^{18}O$. It was set as +/- σ (≈ 70% confidence inteval)

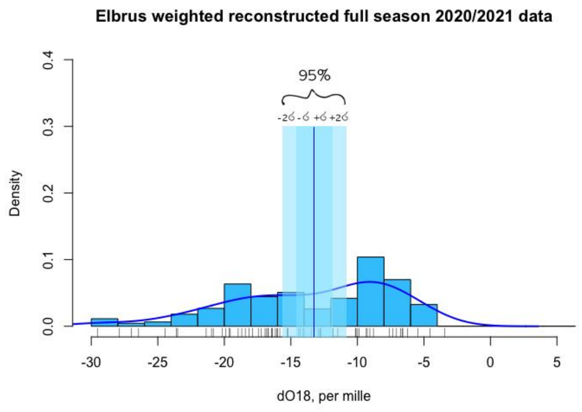


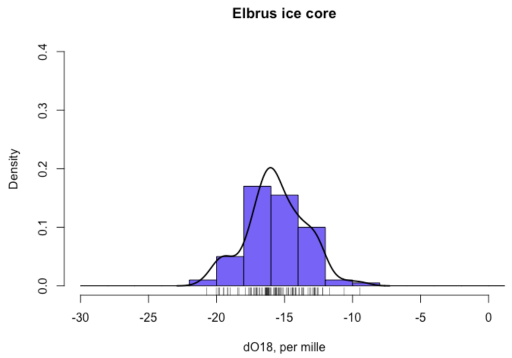


Djankuat ice surface probing
20 Aug 2017

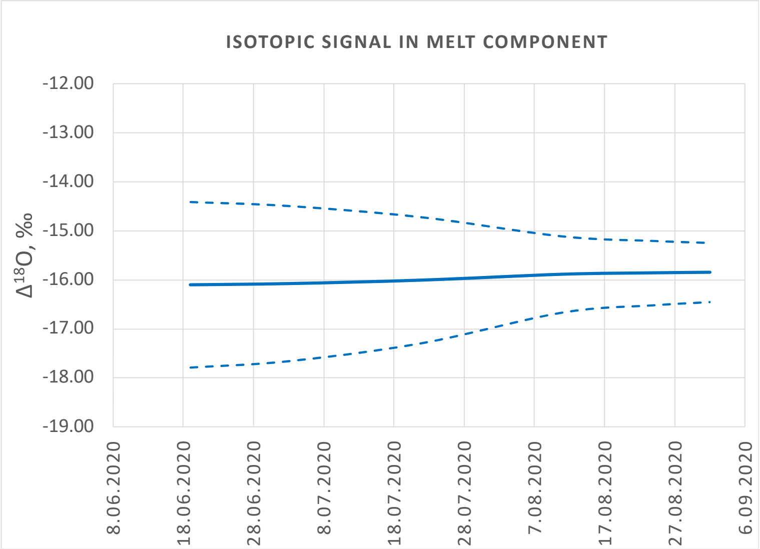


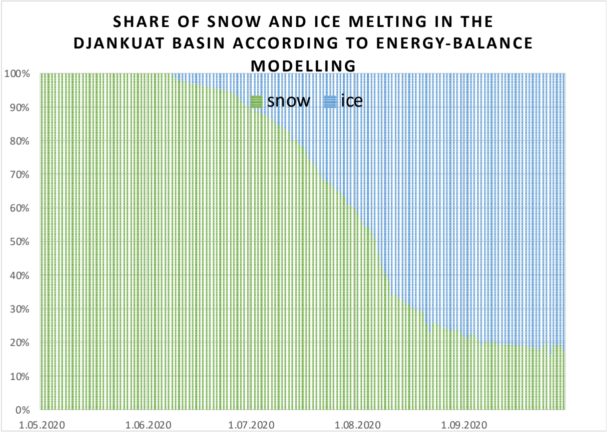
13 Estimating melt component isotopic signal: **3. SNOW&ICE**

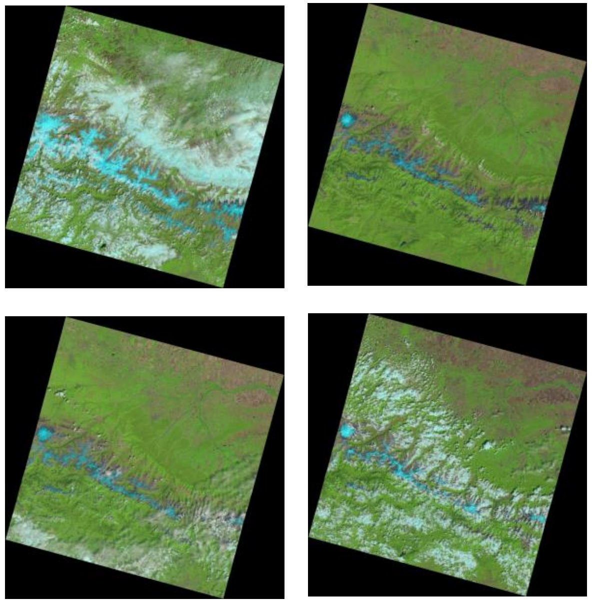




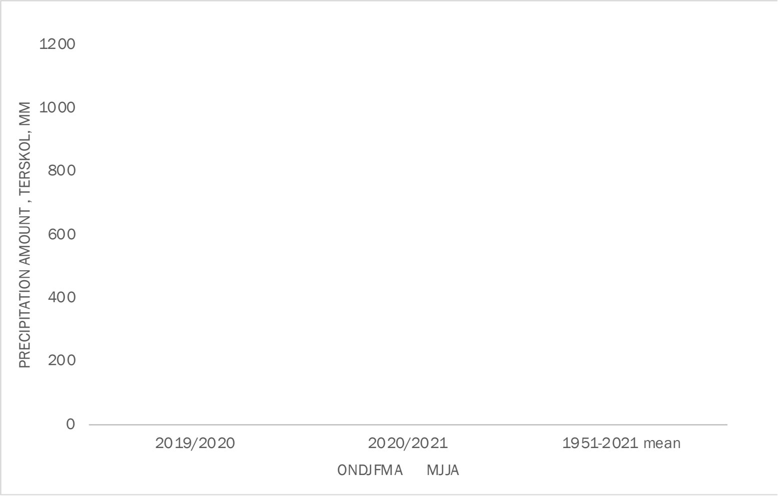
- Final value of melt component isotopic signal is calculated as weighted mean between mean $\delta^{18}O$ in snow cover and ice
- Weights are appointed according to snow coverage share for each date determined Using the Landsat imagery

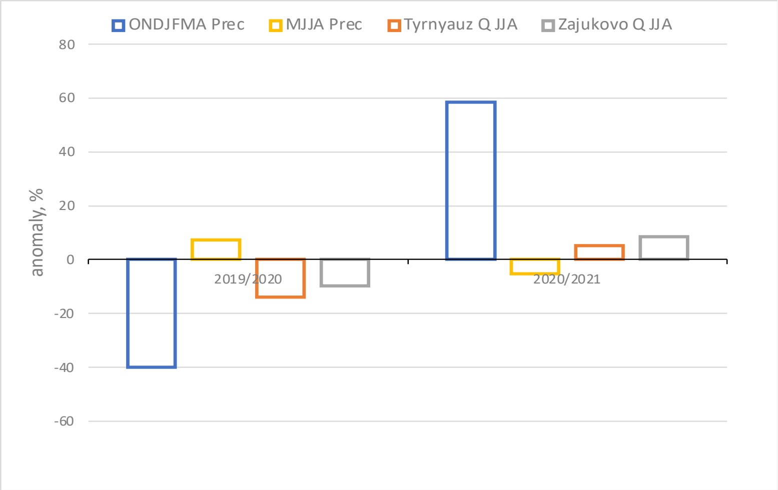




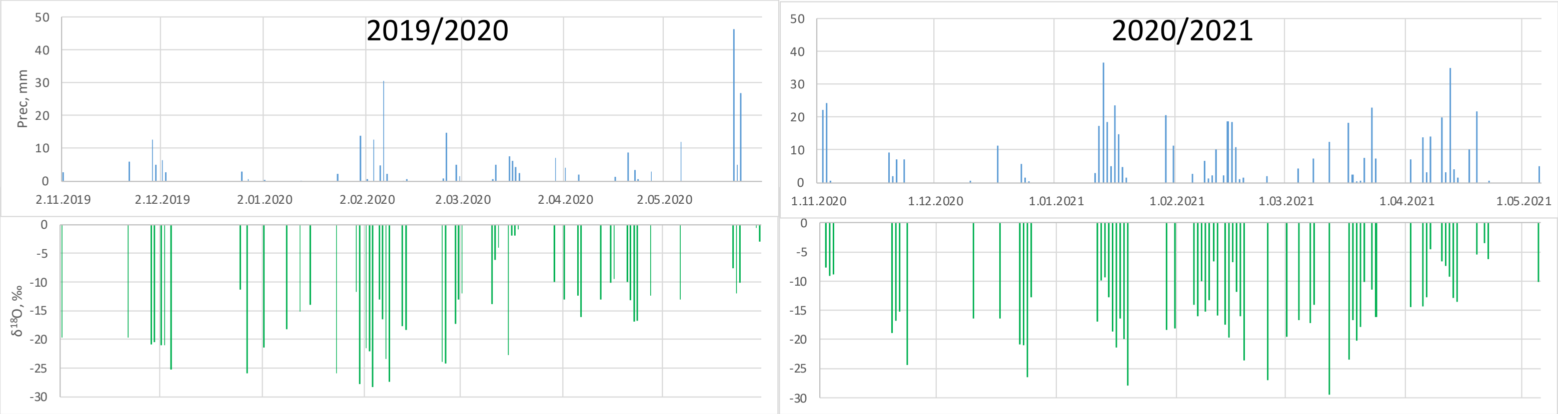


14 2019/2020 and 2020/2021 from long-term perspective

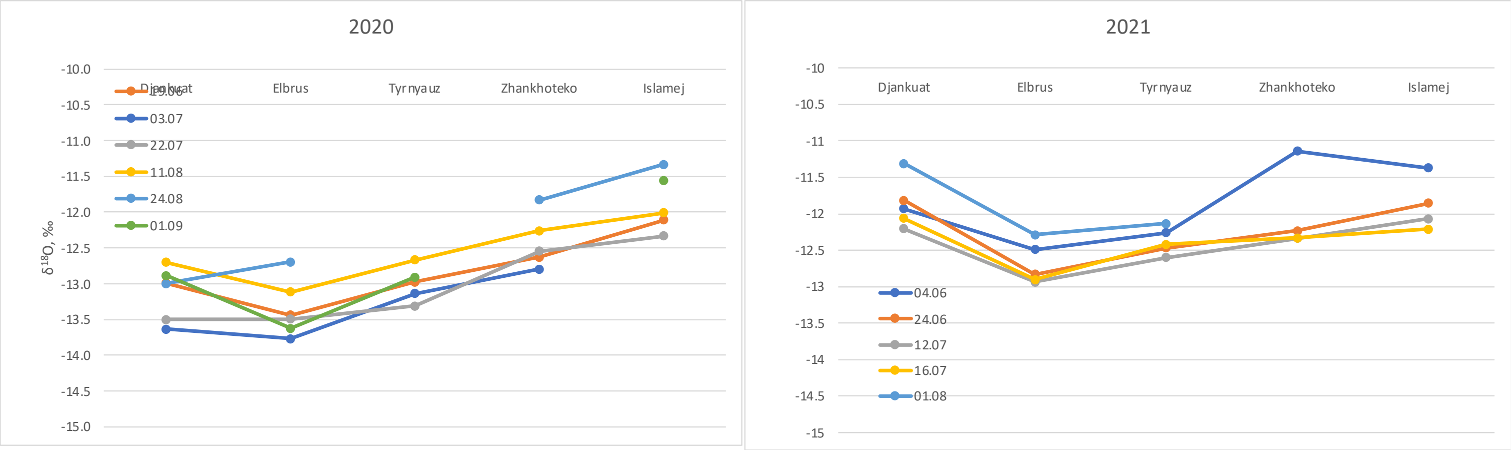




- Winter precipitation amount and isotopic content



- Change in $\delta^{18}O$ in river flow from upstream to downstream



15 Melt and rainfall runoff from headwaters to lower reaches

2020 2021

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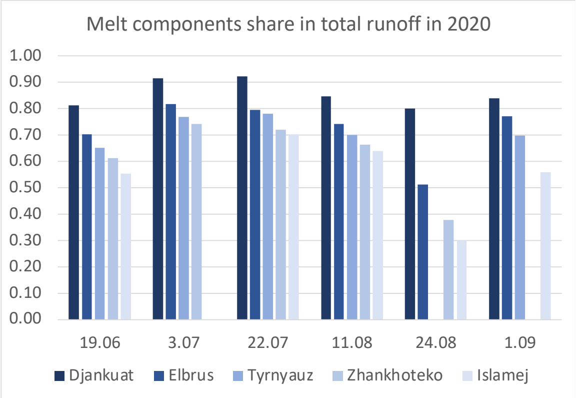
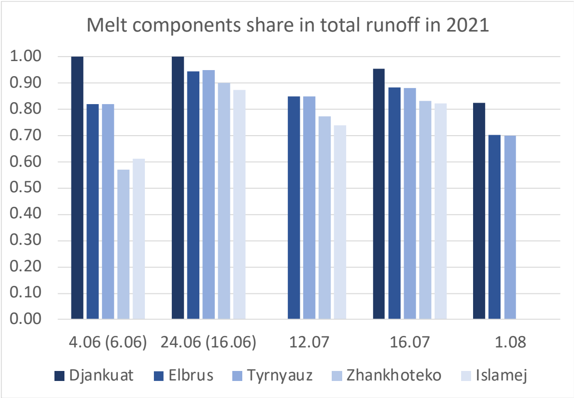
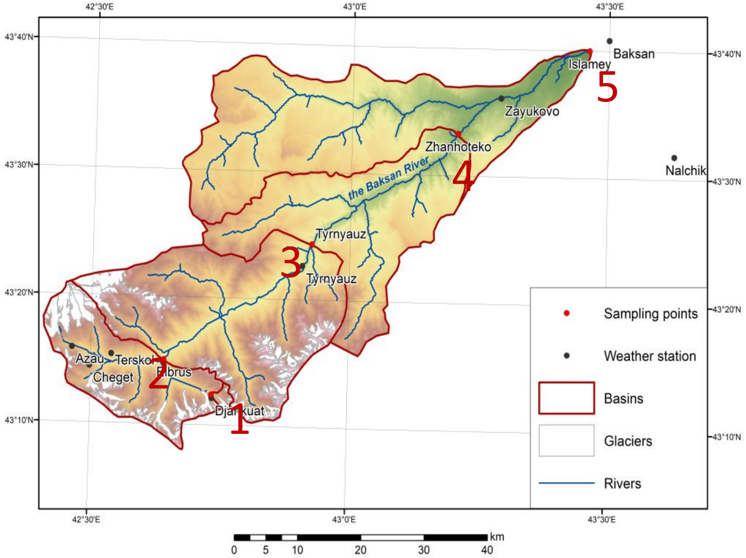
3
4
5

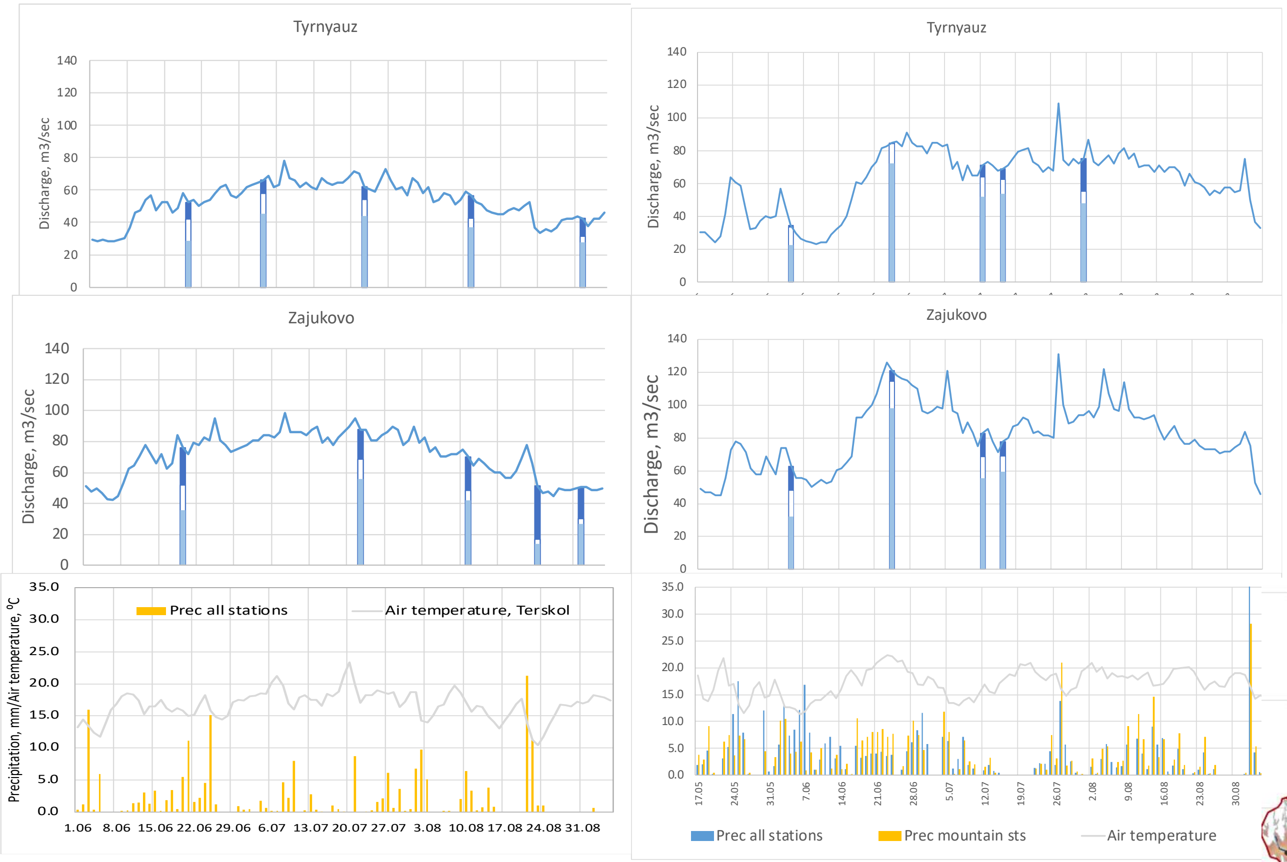




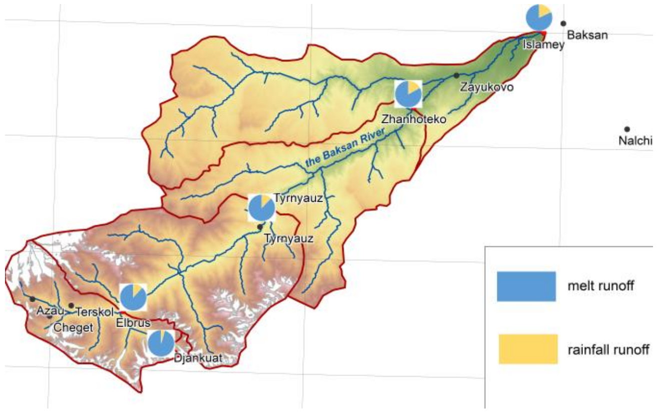


#	Gauge	Basin area, km2	Glaciation rate, %
1	Djankuat	8.7	30
2	Elbrus	376	27
3	Tyrnyauz	1209	16
4	Zhankhoteko	1794	11
5	Islamej	2941	7

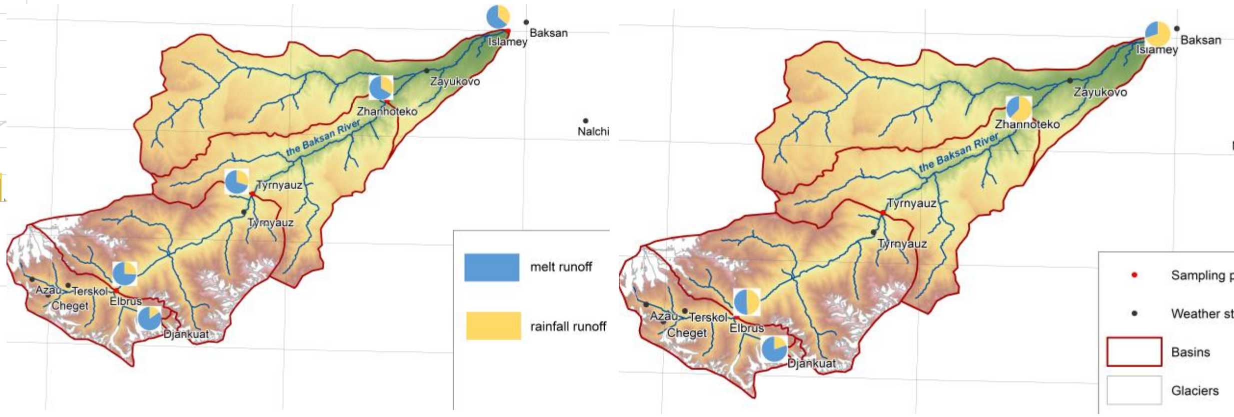
16 Scale effects in streamflow response



After a dry week (16.07.2021)



Before (11.08.2020) and after (24.08.2021) a heavy rainfall (~ 30 mm)



17 Conclusions

- Isotopic method shows consistent results for identification melt and rainfall runoff contribution through different scales and time in glacierized catchment
- It can be used for independent verification hydrological models in glacierized catchments
- The Baksan river that is one of the major river in Terek river basin is most of the summer by 60-80% fed by the melt water in the lower reaches with glaciation ratio of only 7%
- Glacier melt runoff proofs to be a great regulator of interannual fluctuation of the runoff
- Contribution of melt runoff gradually decreases from the end of June to September
- Contribution of rainfall runoff gradually increases from upper to lower reaches
- During dry periods the river is formed from what forms in the uppermost 30% glacierized headwaters
- The rate of response of the Baksan river to rainfall events dramatically increases from upper to lower reaches. The maximum estimated contribution of rainfall runoff amounted to 70% on 24/08/2020 in Islamej