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Cryosphere and related hazards in High Mountain Asia in a changing climate

1–4 November 2022 | Almaty, Kazakhstan

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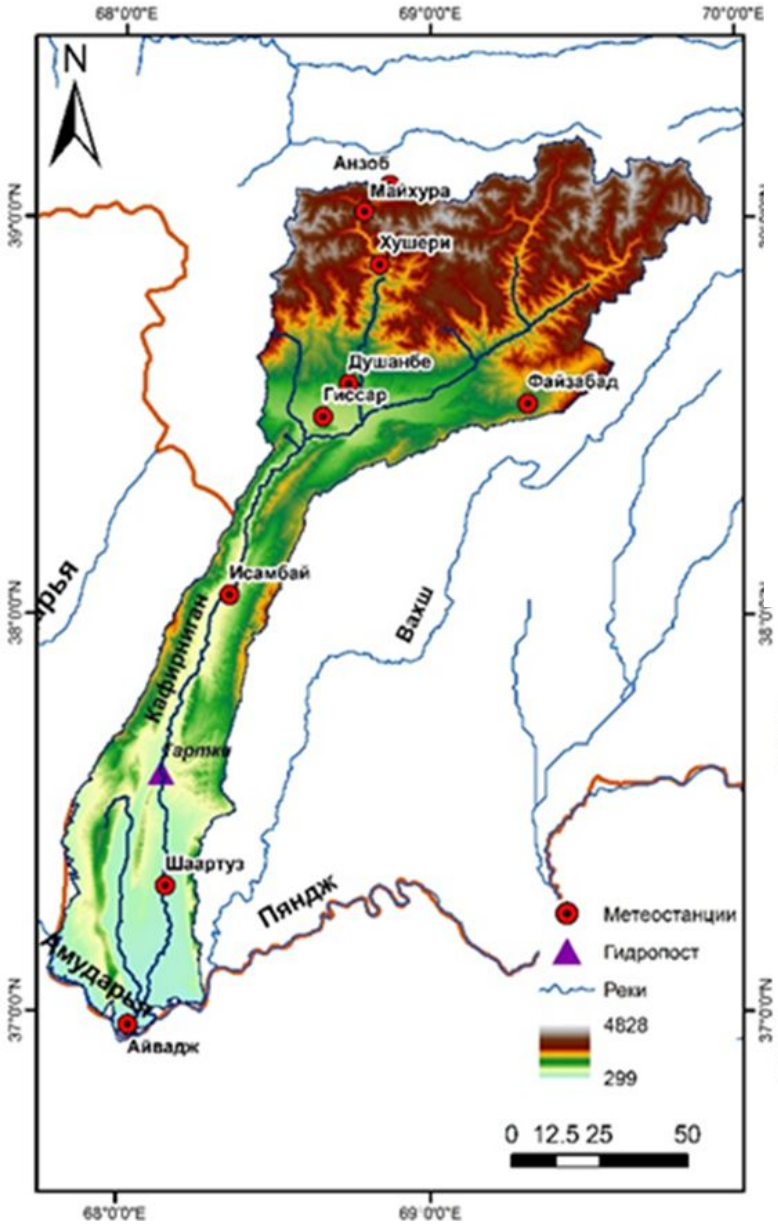
03/10/2022

Glacial and melted snow flow of the Pamir and Pamir-Alai rivers in the modern period (2000-2020)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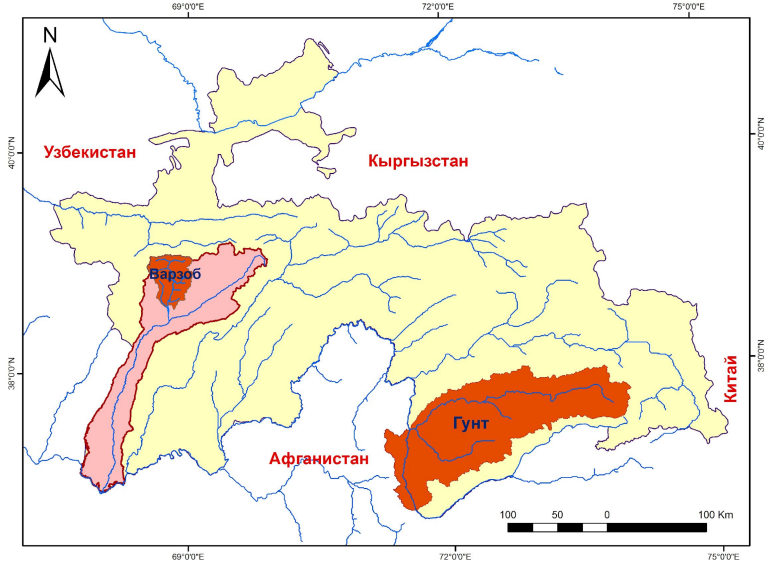
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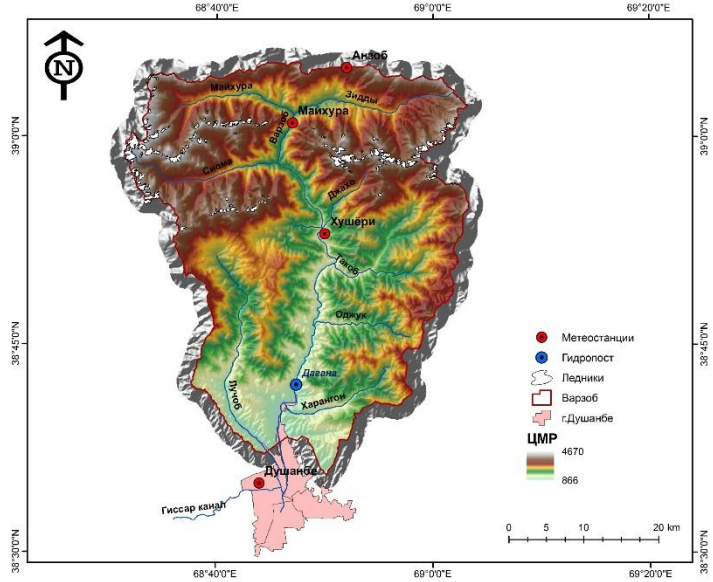
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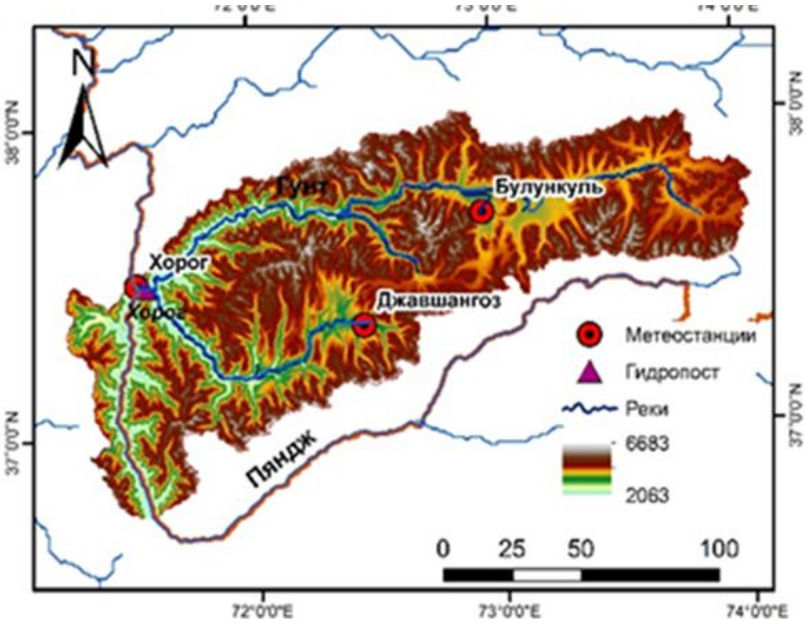
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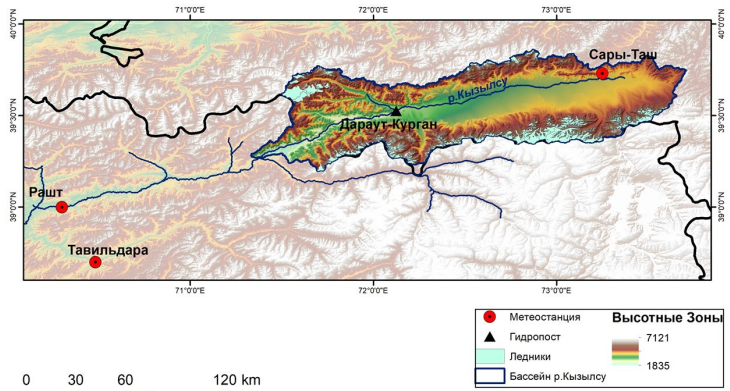
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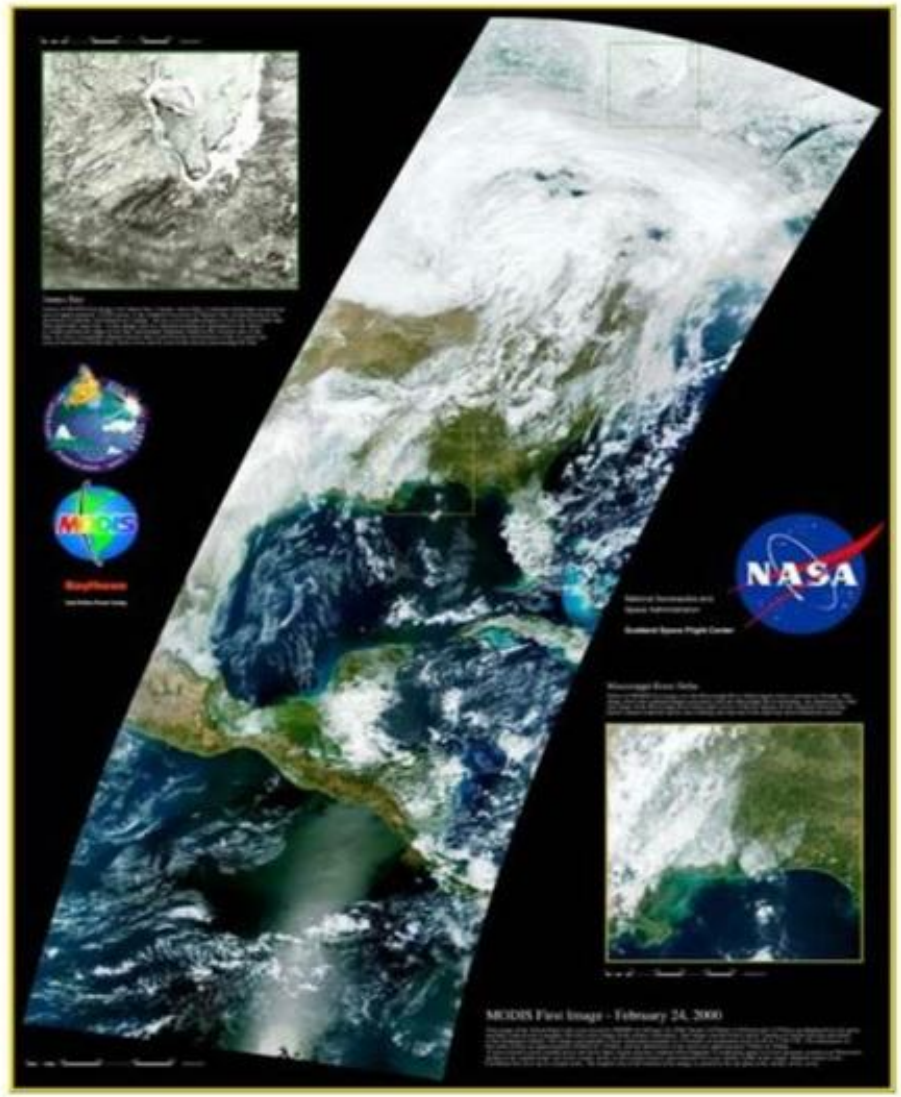
Дараут-Курган
Рашт
Тавильдара
0 30 60 120 km
Метеостанция
Гидропост
Ледники
Бассейн р.Кызылсу
Высотные Зоны
7121
1835

№	Gauging station	Catchment area up to observation point	Mean height of the watershed to the observation point	Glacier area	
		km2	m.a.s.l.		
				km2	as % of the basin area
1	r. Vakhsh - Darband	29500	3600	3243	11
2	r. Kyzylsu - Dombrachi	8388	3050	578,4	6,8
3	r.Gunt - Khorog	13700	4170	634,2	4,2
4	r. Kafirnigan - Tartki	12300	4001	-	<1%
5	r.Varzob - Dagana	1270	2670	40,0	3,0

MODIS Basics

- Moderate Resolution Imaging Spectroradiometer Satellites:
  - Viewing the entire Earth's surface every 1 to 2 days
  - Acquiring data in 36 spectral bands
  - Multiple data products (Atmosphere, Land, Ocean etc.)
  - Important for understanding global environment and earth system models



http://aqua.nasa.gov/doc/viz/media/aqua_orbit_sm.mpg

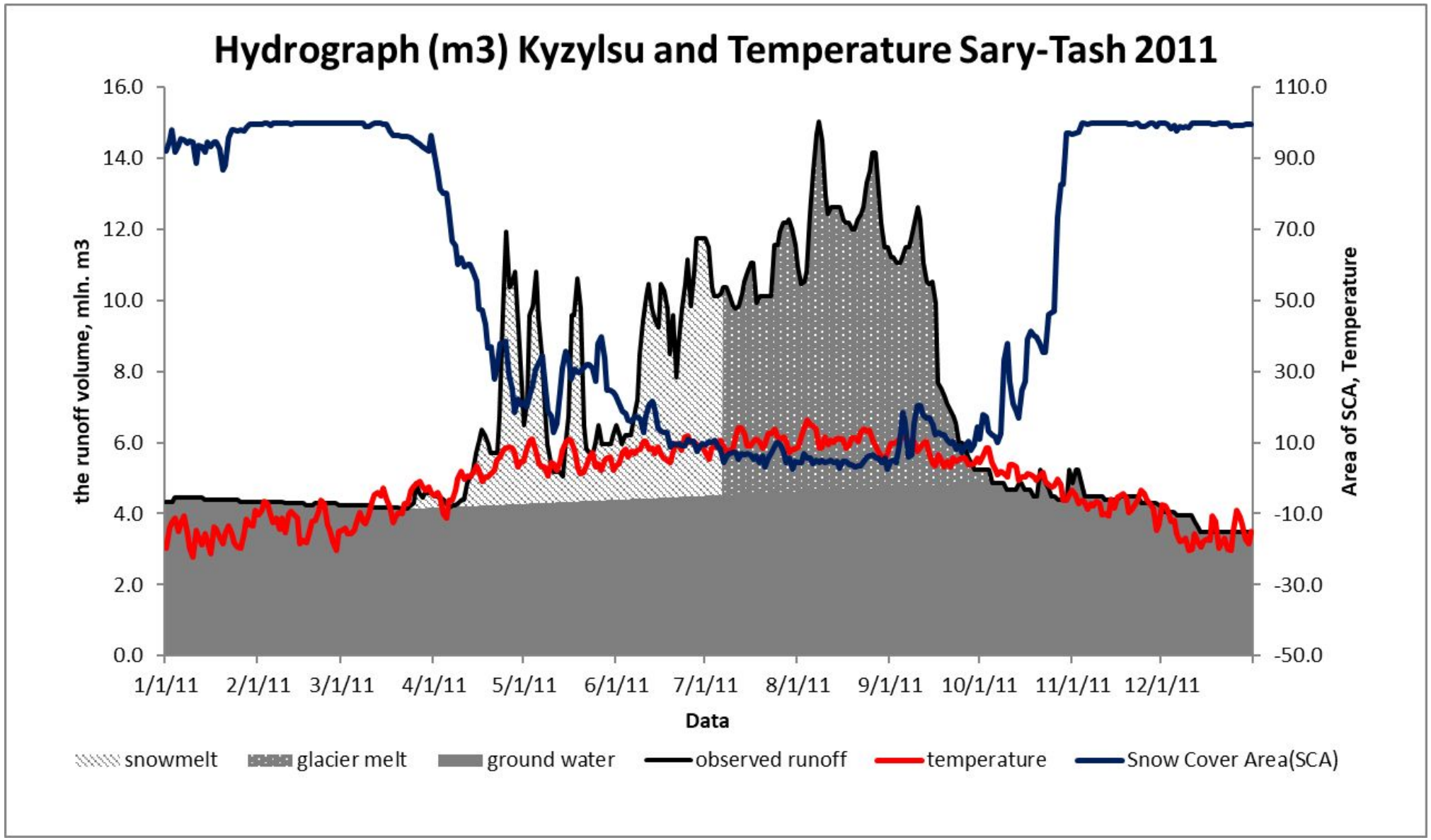
Data

The Moderate Resolution Imaging Spectroradiometer (MODIS) is one of the key instruments on board the American satellites of the EOS series (Terra (EOS AM-1) and Aqua (EOS PM-1)). MODIS sensor has 36 spectral bands with 12-bit radiometric resolution in the visible, near, middle and thermal infrared regions. The spatial resolution of 500 m located in the visible to shortwave infrared (SWIR) spectral regions is well suited for the understanding of the **snow cover**.

Band	Wavelength (nm)	Resolution (m)	**Span (km)**	Temporal resolution
1-2	0.62 - 0.88	250	2300	1–2 days
3-7	**0.46 - 2.16**	**500**	**2300**	
8-19	0.41 - 0.97	1000	2300	
20-25	3.66 - 4.55	1000	2300	
26	1.36 - 1.39	1000	2300	
27-36	6.54 - 14.39	1000	2300	

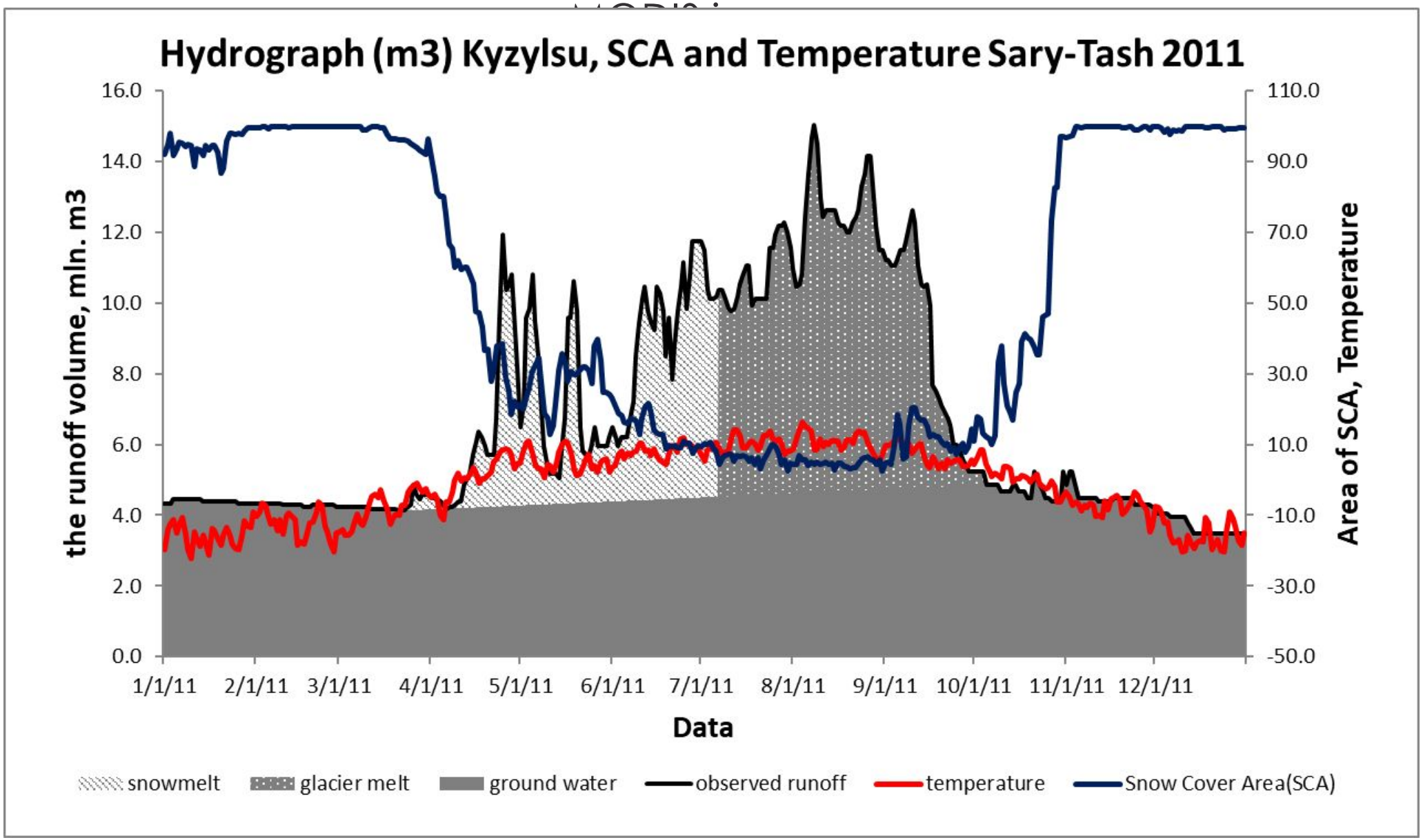
Methodology.

genetic vertical dissection of the hydrograph using MODIS images



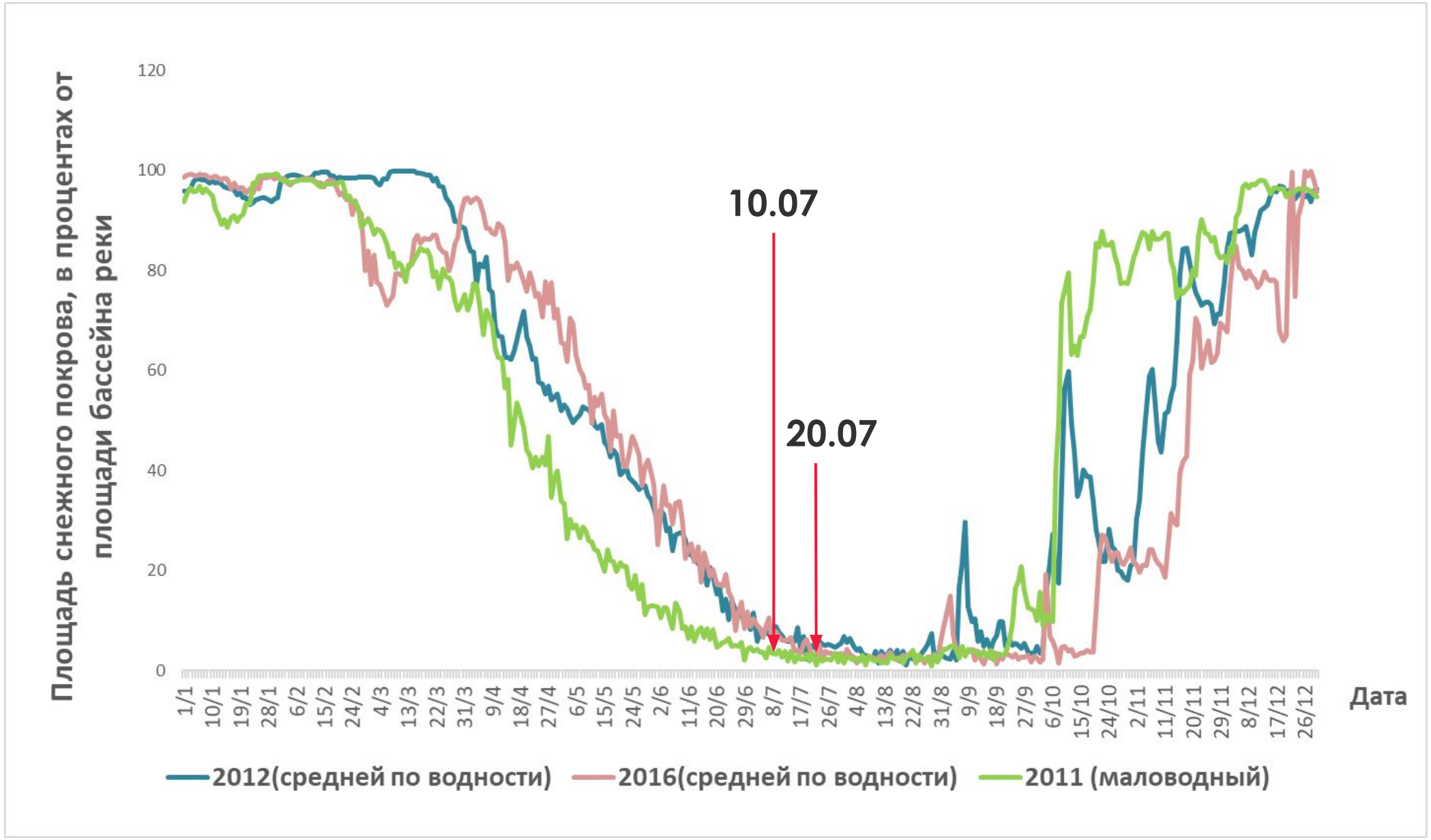
Methodology.

The genetic vertical dissection of the hydrograph on the runoff component with



Results

Component runoff	r. Kyzylsu		
	million, m3	% total runoff	period
observed	2457		
ground water	1605	65	
snowmelt	323	13	23.03-07.07
glacier melt	528	22	08.07-06.10



Daily variation of snow cover according to MODIS imagery data for 2011 dry year, 2012, 2016 average water years for the Gunt River basin.

Years	the volume of runoff of the main river alienation					
	ground runoff		Melted snow runoff		Melted glacial runoff	
	million m3	%	million m3	%	million m3	%
r. Gunt - Khorog						
2011 dry year	1220	55	359 (23.04-10.07)	16	645 (11.07-20.10)	29
2012 average water year	1649	51	961 (26.05-22.07)	30	596 (23.07-06.10)	17
2016 average water year	1471	47	1148 (08.05-20.07)	36	530 (21.07-11.10)	17

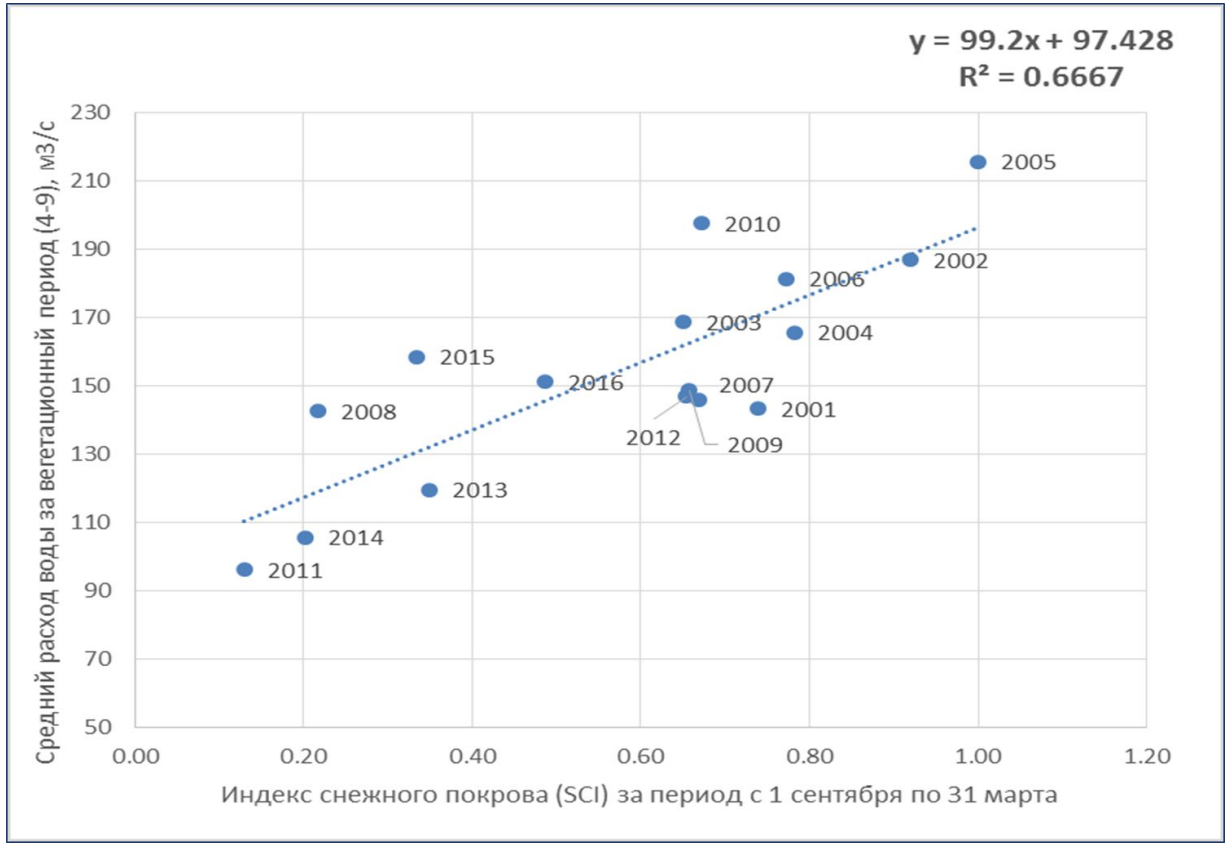
Snow cover calculation methodology

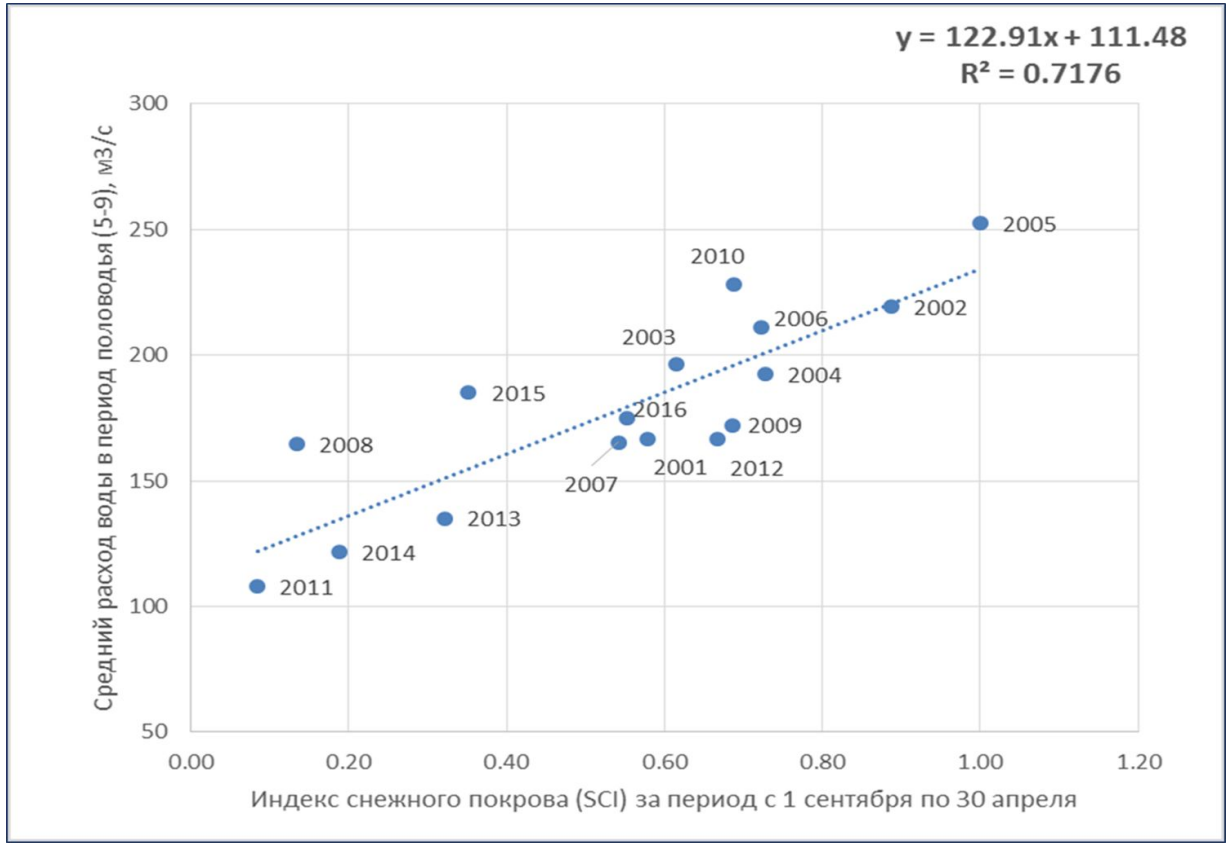
To consider the spatial and temporal variability of snow cover in the basin, a snow cover index (SCI) was introduced, which is the total snow cover area (SCA) for a hydrological year.

$$SCI_t = \sum_{n=1}^{n=365/366} SCA_i$$

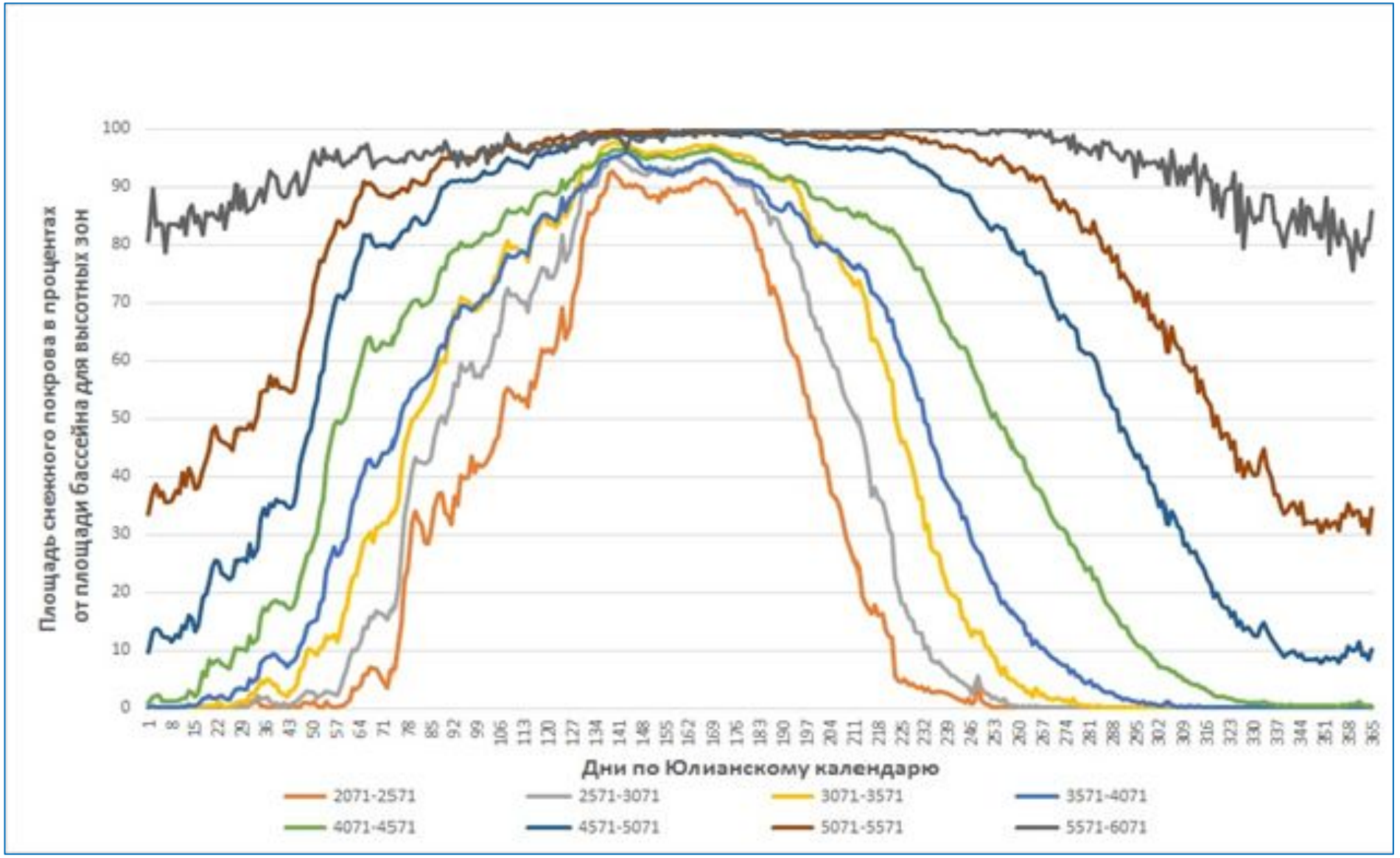
- Snow Cover Index for the year t
- Snow cover area for days n, from September 1 to August 31 of the coming year.

forecast of the water content of the Gunt River in vegetation periods (April-September) and for the flood period (May-September) based on the Snow Cover Index (SCI).



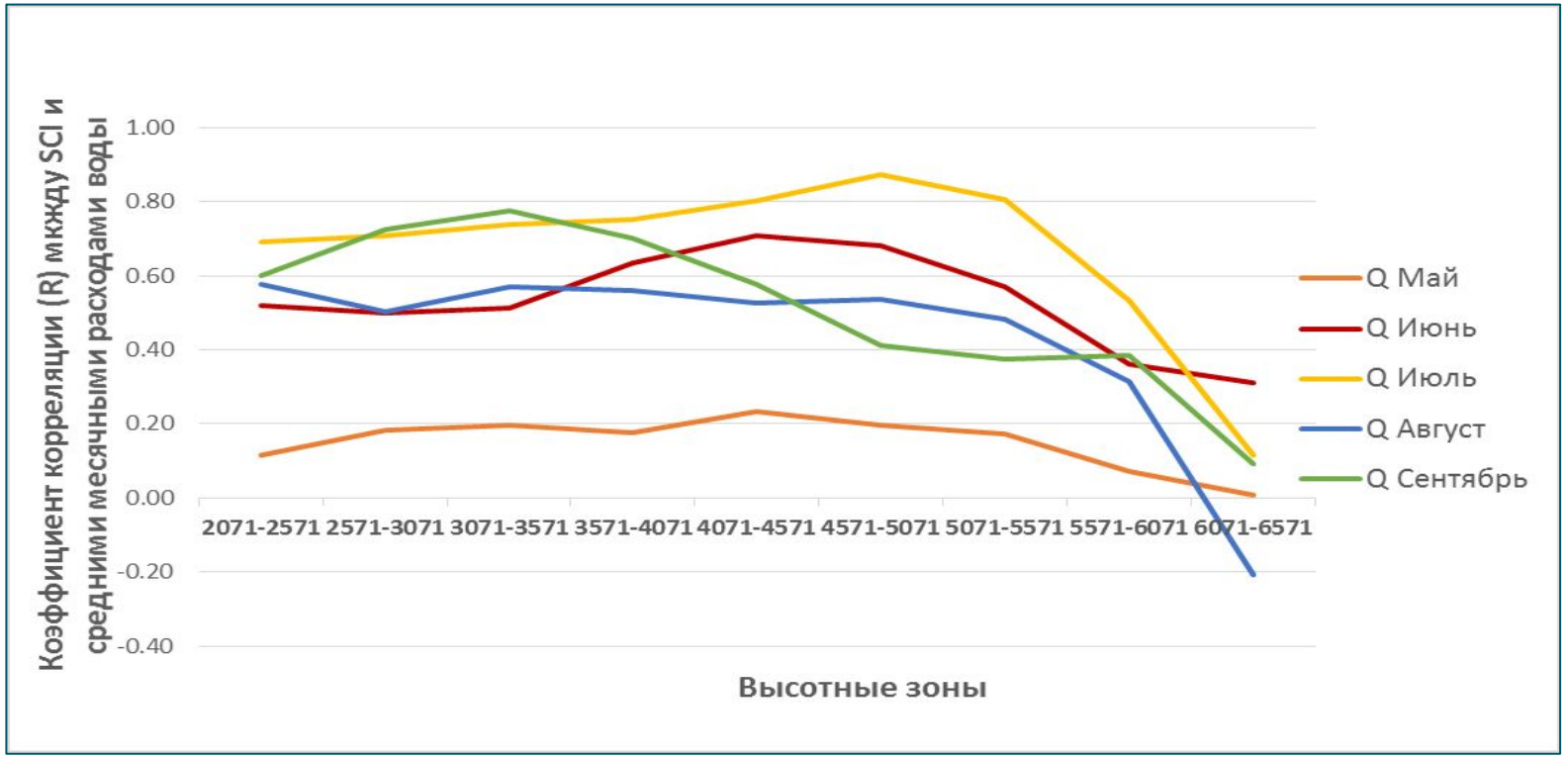


Calculation of the snow cover area (SCA) for altitudinal zones in 500 m.



the narrowness of dependences of the average monthly runoff of in the high-water period with the index (SCI)

Средний месячный	Высотные зоны								
	2071-2571	2571-3071	3071-3571	3571-4071	4071-4571	4571-5071	5071-5571	5571-6071	6071-6571
Q Май	0.12	0.18	0.20	0.18	0.23	0.20	0.17	0.07	0.01
Q Июнь	0.52	0.50	0.51	**0.63**	**0.71**	**0.68**	0.57	0.36	0.31
Q Июль	0.69	0.71	0.74	**0.75**	**0.80**	**0.87**	**0.81**	0.53	0.12
Q Август	0.58	0.50	**0.57**	**0.56**	**0.53**	**0.54**	0.48	0.31	-0.21
Q Сентябрь	0.60	**0.72**	**0.78**	**0.70**	0.58	0.41	0.38	0.38	0.09



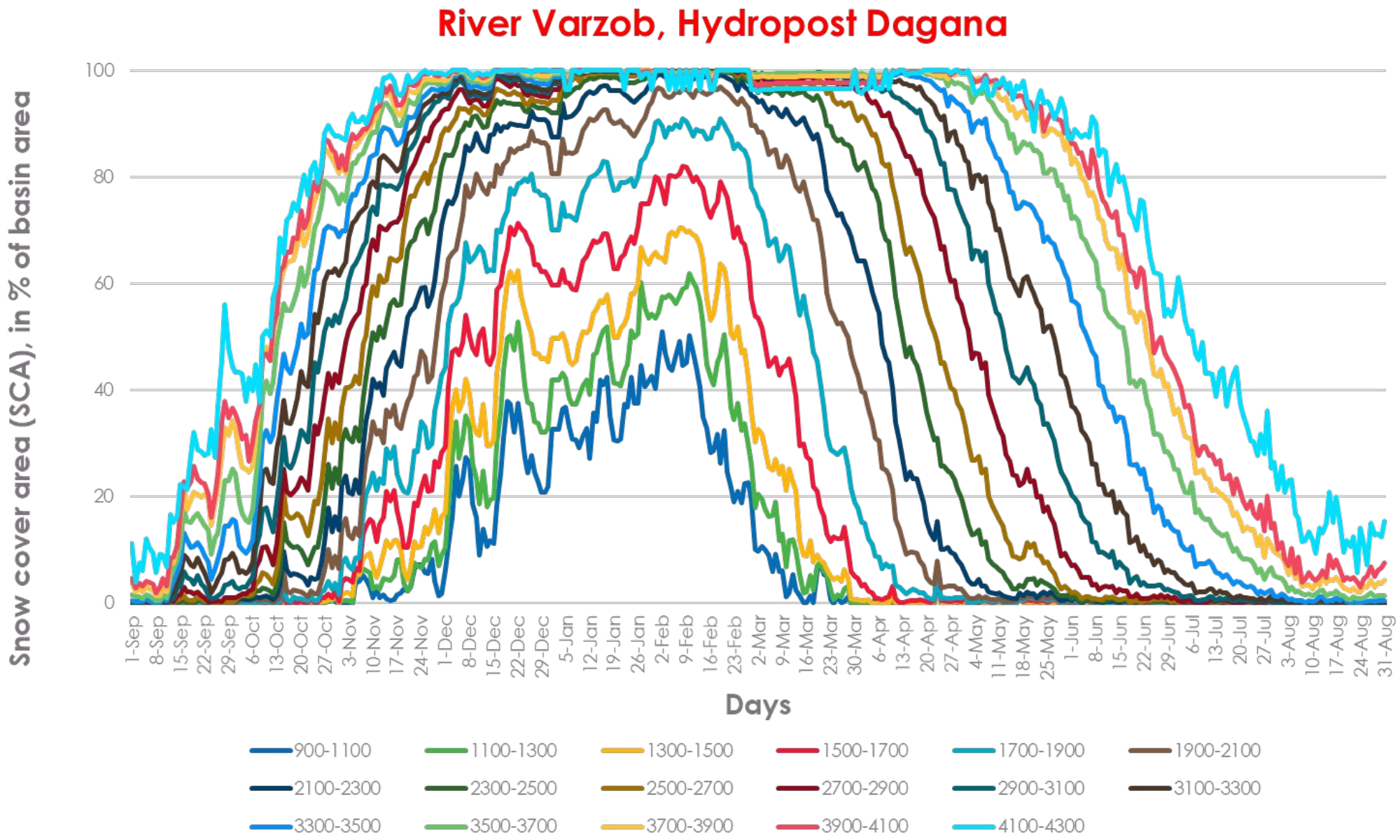
Calculation results of the correlation coefficients of the average monthly water discharges of the Kafirnigan River and the SCI index for altitudinal zones

months	Altitude zones								
	436-936	936-1436	1436-1936	1936-2436	2436-2936	2936-3436	3436-3936	3936-4436	4436-4712
April	0,54	0,58	0,52	0,51	0,48	0,45	0,42	0,40	0,49
May	0,25	0,34	0,52	0,59	0,53	0,46	0,36	0,31	0,28
June	0,46	0,56	0,63	**0,71**	**0,73**	**0,72**	0,62	0,52	0,28
July	0,62	**0,68**	**0,74**	**0,80**	**0,84**	**0,87**	**0,78**	0,56	0,05
August	0,62	0,65	**0,77**	**0,85**	**0,85**	**0,87**	**0,78**	0,59	0,08
September	0,43	0,60	**0,72**	**0,78**	**0,77**	**0,70**	0,63	0,56	0,00

Equations of linear dependence of average monthly river runoff with the SCI snow cover index for altitude zones at 500 m.

Months	Altitude zone	Equations	Correlation coefficient (R)
1	2	3	4
For Kafirnigan River			
April	1936-2436	$245SCI_{9-3} + 207$	0,67
May	2936-3436	$245SCI_{9-4} + 327$	0,77
June	2936-3436	$305SCI_{9-5} + 247$	0,82
July	2936-3436	$286SCI_{9-6} + 108$	0,91
August	2936-3436	$118SCI_{9-7} + 58,4$	0,87
September	2936-3436	$36,6SCI_{9-8} + 49,1$	0,74
For Gunt River*			
June	4071-4571	$186SCI_{9-5} + 125$	0,71
July	4571-5071	$289SCI_{9-6} + 123$	0,87
August	3071-3571	$99,9SCI_{9-7} + 147$	0,57
September	3071-3571	$52,2SCI_{9-8} + 76,0$	0,78

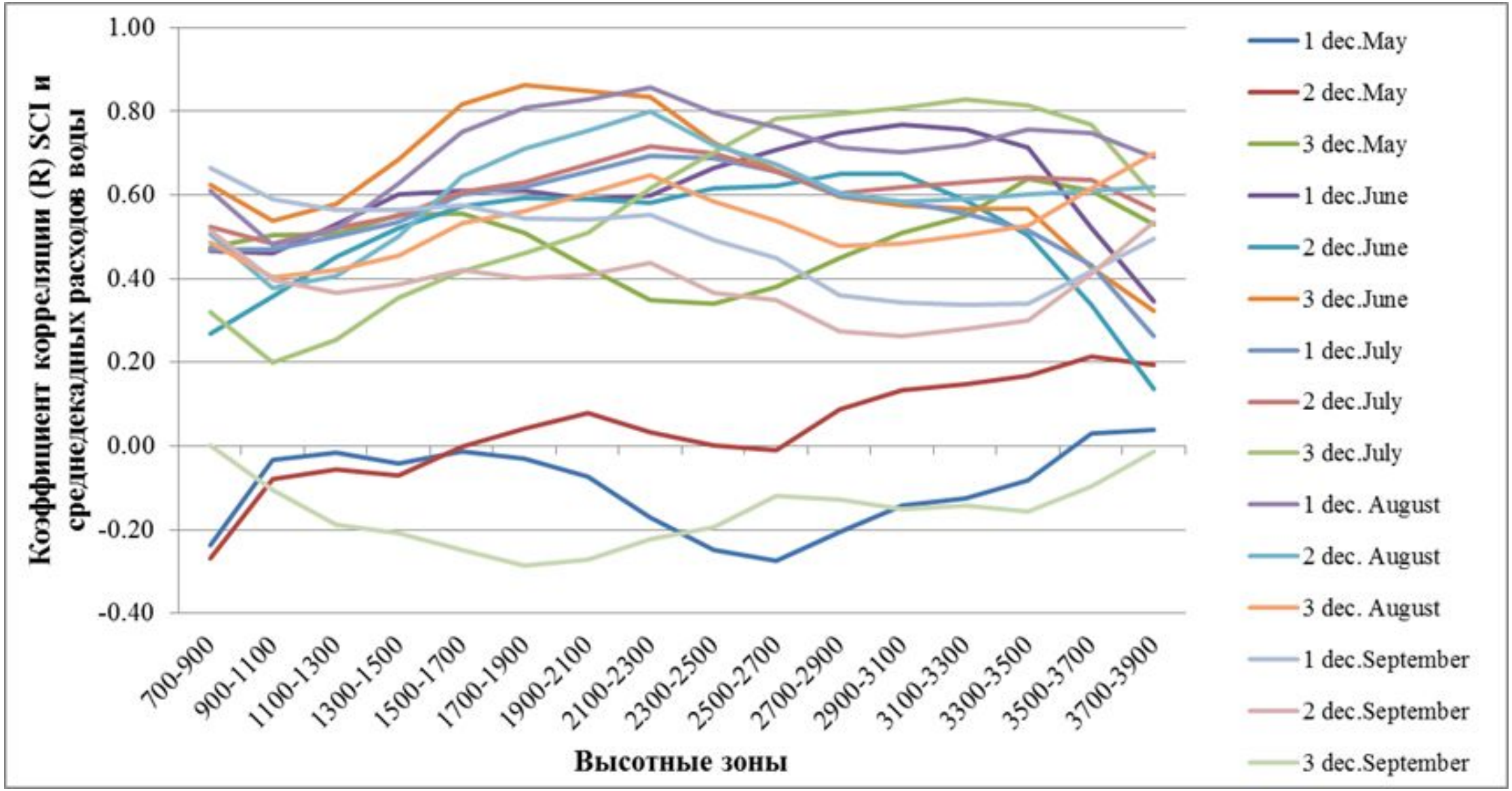
Calculation of Snow Cover Area (SCA), for high-altitude zones after 200 m



Correlation coefficient (R) of **average decade (ten-day)** water discharges and SCI index for high-altitude zones on the Varzob River

	700-900	900-1100	1100-130	1300-150	1500-170	1700-190	1900-210	2100-230	2300-250	2500-270	2700-290	2900-310	3100-330	3300-350	3500-370	3700-390
1 dec.May	-0.24	-0.03	-0.02	-0.04	-0.01	-0.03	-0.07	-0.17	-0.25	-0.28	-0.20	-0.14	-0.12	-0.08	0.03	0.04
2 dec.May	-0.27	-0.08	-0.06	-0.07	0.00	0.04	0.08	0.03	0.00	-0.01	0.09	0.13	0.15	0.17	0.21	0.19
3 dec.May	0.48	0.50	0.51	**0.55**	**0.56**	0.51	0.43	0.35	0.34	0.38	0.45	0.51	0.55	**0.64**	**0.61**	0.53
1 decJune	0.47	0.46	0.53	**0.60**	**0.61**	**0.61**	**0.59**	**0.60**	**0.66**	**0.71**	**0.75**	**0.77**	**0.76**	**0.71**	0.52	0.35
2 decJune	0.27	0.36	0.45	0.52	**0.57**	**0.59**	**0.59**	**0.58**	**0.62**	**0.62**	**0.65**	**0.65**	**0.59**	0.50	0.34	0.14
3 decJune	0.63	0.54	**0.58**	**0.69**	**0.82**	**0.86**	**0.85**	**0.83**	**0.73**	**0.66**	**0.60**	**0.58**	**0.57**	**0.57**	0.43	0.32
1 decJuly	0.47	0.47	0.50	0.54	**0.60**	**0.62**	**0.66**	**0.69**	**0.69**	**0.66**	**0.60**	**0.58**	**0.55**	0.52	0.43	0.26
2 decJuly	0.52	0.48	0.52	**0.55**	**0.61**	**0.63**	**0.67**	**0.72**	**0.70**	**0.66**	**0.61**	**0.62**	**0.63**	**0.64**	**0.64**	**0.56**
3 decJuly	0.32	0.20	0.25	0.35	0.42	0.46	0.51	**0.62**	**0.70**	**0.78**	**0.79**	**0.81**	**0.83**	**0.81**	**0.77**	**0.60**
1 dec. August	**0.61**	0.48	0.52	**0.63**	**0.75**	**0.81**	**0.83**	**0.86**	**0.80**	**0.76**	**0.71**	**0.70**	**0.72**	**0.76**	**0.75**	**0.69**
2 dec. August	0.51	0.38	0.41	0.50	**0.64**	**0.71**	**0.75**	**0.80**	**0.72**	**0.67**	**0.60**	**0.58**	**0.59**	**0.60**	**0.61**	**0.62**
3 dec. August	0.49	0.40	0.42	0.46	0.53	**0.56**	**0.61**	**0.65**	**0.58**	0.54	0.48	0.48	0.50	0.53	**0.62**	**0.70**
1 dec.September	**0.66**	**0.59**	**0.56**	**0.56**	0.58	0.54	0.54	**0.55**	0.49	0.45	0.36	0.34	0.34	0.34	0.42	0.49
2 dec.September	0.52	0.40	0.37	0.39	0.42	0.40	0.41	0.44	0.37	0.35	0.27	0.26	0.28	0.30	0.41	0.54
3 dec.September	0.00	-0.11	-0.19	-0.21	-0.25	-0.28	-0.27	-0.22	-0.19	-0.12	-0.13	-0.15	-0.14	-0.16	-0.10	-0.01

Correlation coefficient (R) of **the average decade (ten-day)** water discharges and SCI index for high-altitude zones on the Varzob River



Using the linear dependence of the SCI index and **the average decades (ten-day)** water discharge on the Varzob River, equations were obtained for predicting runoff river for decades. The best results were in the months of seasonal snowmelt. The reliability of forecasts taking into account the permissible forecast error, it amounted to 78-100% (Varzob River).

Decade	Elevation zone	Equation	Correlation coefficient (R)	The reliability of forecasts for period 2010-2018, in %
2 decade of April	**2100-2300**	55.01* SCI + 42.024	0.58	78
3 decade of May	**1500-1700**	33.548*SCI + 88.811	0.56	100
1 decade of June	**2700-2900**	91.565*SCI + 39.746	0.75	100
2 decade of June	**2700-2900**	66.534*SCI + 61.154	0.65	100
3 decade of June	**2100-2300**	67.259*SCI + 54.519	0.60	100
1 decade of July	**2100-2300**	52.334*SCI + 61.532	0.69	100
2 decade of July	**2100-2300**	49.125*SCI + 47.773	0.72	100
3 decade of July	**2700-2900**	70.668*SCI + 13.595	0.79	89
3 decade of July	**2900-3100**	78.462*SCI + 7.5133	0.81	89
1 decade of August	**2100-2300**	46.3*SCI + 21.451	0.86	89
2 decade of August	**2100-2300**	32.015*SCI + 22.25	0.80	100
3 decade of August	**2100-2300**	19.599*SCI + 22.007	0.65	100
1 decade of September	**2100-2300**	15.439*SCI + 17.844	0.55	100

Conclusion

1. One of the main advantages of the proposed method is a qualitative and reliable forecast of the high-altitude rivers runoff using MODIS satellite images processed in the MODSNOW program, which is important for the rivers runoff forecasting with mid and high-mountain basins and the basins, where ground-based observations of snow cover are not currently being conducted.
2. Forecasts for the rivers Pamir and Pamir Alay are very important for flood, mud/debris flows prevention.
3. An analysis of the correlation coefficients of the Snow Cover Index (SCI) calculated for high-altitude zones in 500 m. and 200 m. with average monthly and ten-day (decade) water discharge showed the close relation for months, where melt snow and glacial runoff plays a decisive role in the river flow formation (April-September).

Thank you

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