Future climate and runoff projections in Naltar Catchment, Upper Indus Basin from CORDEX-South Asia models and hydrological modelling

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Research Objective

- ✓ Assess if the ‘Karakoram anomaly’ (e.g. Faronotti et al., Nature Geociences, 2020) i.e. a slower retreat of glaciers in the Karakoram region can be confirmed for the Naltar catchment, in the southern side of the Karakoram (Upper Indus Basin)
- ✓ To examine the overall performance of Physical Based Distributed Snow Land and Ice Model PDSLIM model to compute snow and ice melt contribution to runoff regime and floods.
- ✓ Project changes of the hydrological regime under Climate changes scenarios

Naltar Catchment

The Naltar catchment covers up to **243** km^2 .

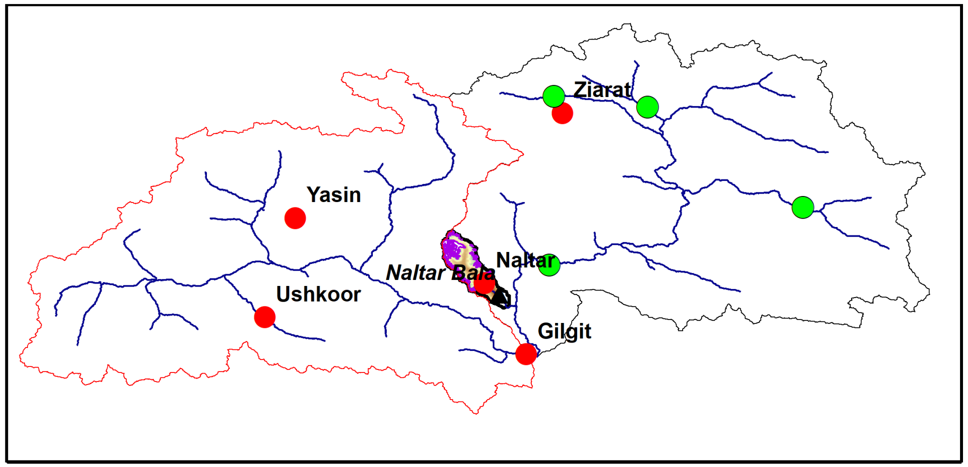
Around **42.8** km^2 area is covered with glaciers.

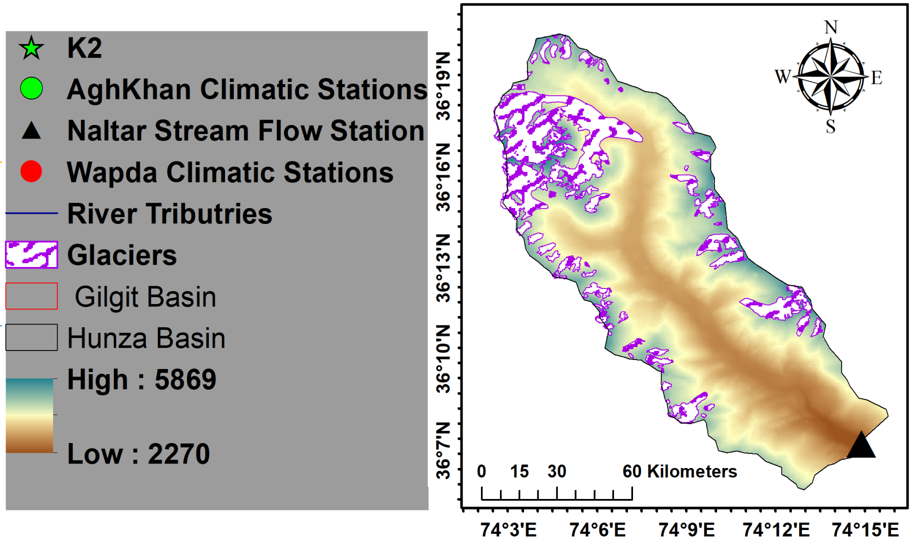
The largest glacier is Shani glacier (area **19 km^2**)

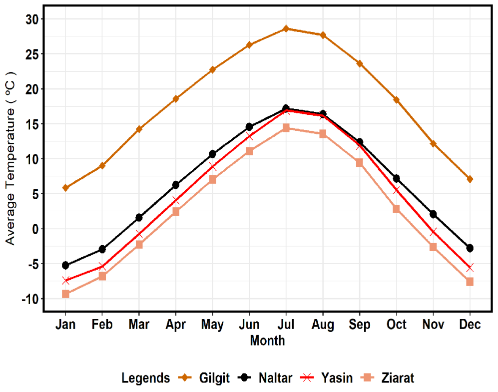
It is situated in Hunza basin about 42 km away from Gilgit city and 208 km from **K2 (the second largest mountain range in world)** in the Gilgit-Baltistan region of Pakistan, in the southern side of Karakoram

The elevation of Naltar catchment varies from 2270 m to 5869 m with mean elevation 4064 m.

The average annual precipitation and temperature recorded at Naltar station are **685 mm and 6.5^{o}C**







Hourly P, T, RH, V, p, R meteorological station and daily runoff in Naltar station close to the outlet

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List of CORDEX South Asia (WAS-44) Regional Climate Model experiments, deriving GCMS, available RCPs

RCM	RCM description	Contributing CORDEX modelling center	SR NO	Driving CMIP5 GCM	Contributing CMIP5 modeling center	RCP26	RCP45	RCP85
IITM-RegCM4	The Abdus Salam International Centre for Theoretical Physics (ICTP) Regional Climate Model version 4 (RegCM4; (Giorgi et al. 2012))	Centre for Climate Change Research (CCCR), Indian Institute of Tropical Meteorology (IITM), India	RCM1	CCCma-CanESM2	Canadian Center for Climate Modelling and Analysis (CCCma), Canada	×	✓	✓
			RCM2	CSIRO-QCCCE-CSIRO	Commonwealth Scientific and Industrial Research, Australia	×	✓	✓
			RCM3	IPSL-IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	×	✓	✓
			RCM4	MPI-M-MPI-ESM	Max Plank Institute for Meteorology, Germany (MPI-M)	×	✓	✓
			RCM5	NOAA-GFDL-GFDL-ESM2M	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory (GFDL)	×	✓	✓
SMHI-RCA4	Rossby Centre Regional Atmospheric Model version 4 (RCA4; (Samuelsson et al. 2011))	Rossby Centre, Swedish Meteorological and Hydrological Institute (SMHI), Sweden	RCM6	CCCma-CanESM2	Canadian Center for Climate Modelling and Analysis (CCCma), Canada	×	✓	✓
			RCM7	CNRM-CERFACS	National Centre for Meteorological Research, France	×	✓	✓
			RCM8	CSIRO-QCCCE-CSIRO	Commonwealth Scientific and Industrial Research, Australia	×	✓	✓
			RCM9	ICHEC-EC-EARTH	Irish Center for High-End Computing, European Consortium	✓	✓	✓
			RCM10	IPSL-IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	×	✓	✓
			RCM11	MIROC-MIROC5	Model for Interdisciplinary Research on Climate (MIROC), Japan, Agency for Marine-Earth Science and Tech	✓	✓	✓
			RCM12	MOHC-HadGEM2-ES	Met Office Hadley Centre for Climate Science	✓	✓	✓
			RCM13	MPI-M-MPI-ESM	Max Plank Institute for Meteorology, Germany (MPI-M)	✓	✓	✓
			RCM14	NCC-NorESM1-M	Norwegian Climate Center (NCC), Norway	✓	✓	✓
			RCM15	NOAA-GFDL-GFDL-ESM2M	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory (GFDL)	×	✓	✓
MPI-CSC-REMO2009	MPI Regional model 2009 (REMO2009; (Teichmann et al. 2013)	Climate Service Center (CSC), Germany	RCM16	MPI-M-MPI-ESM	Max Plank Institute for Meteorology, Germany (MPI-M)	×	✓	✓

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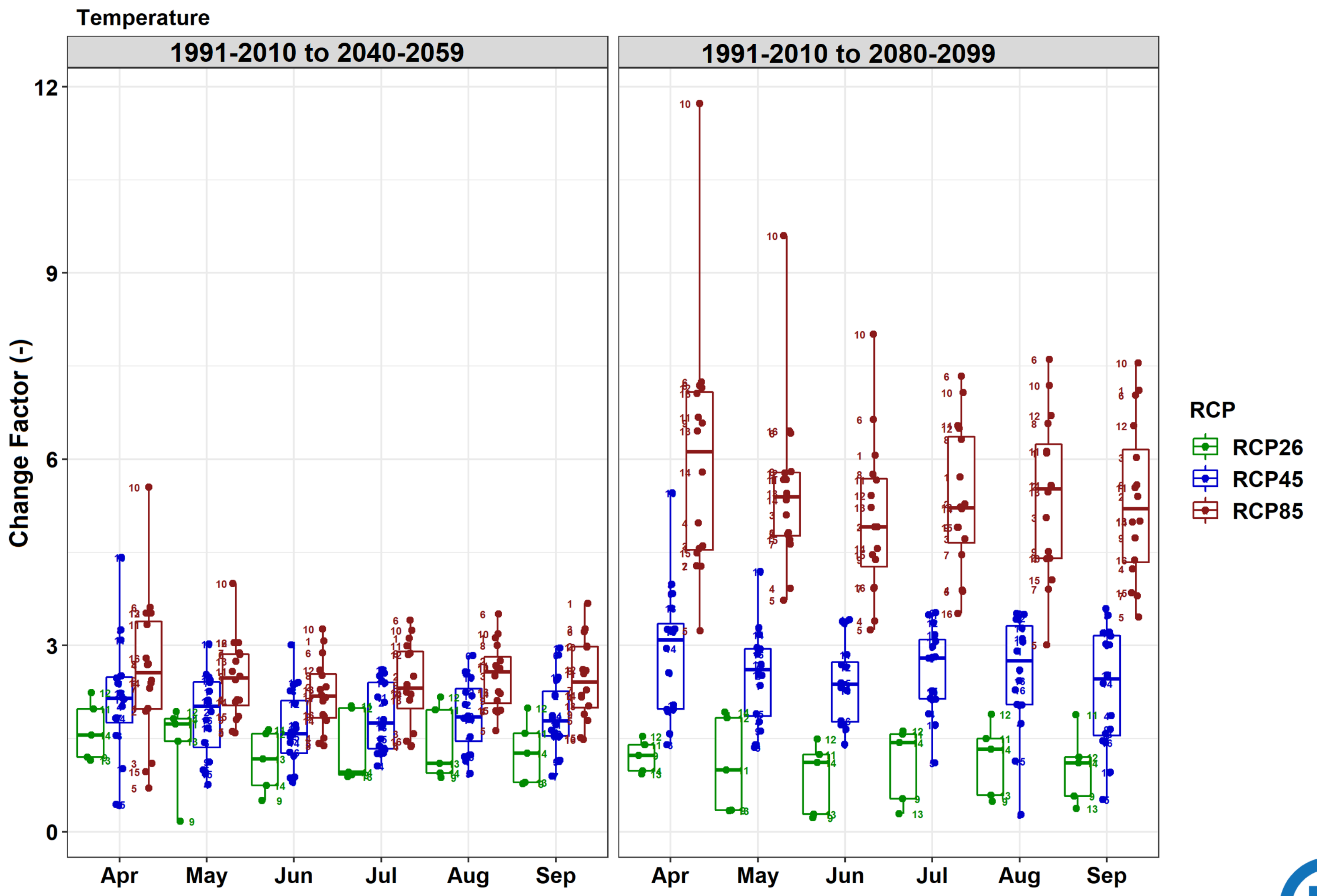
Seasonal cycle of additive climatological change factor of Temperature



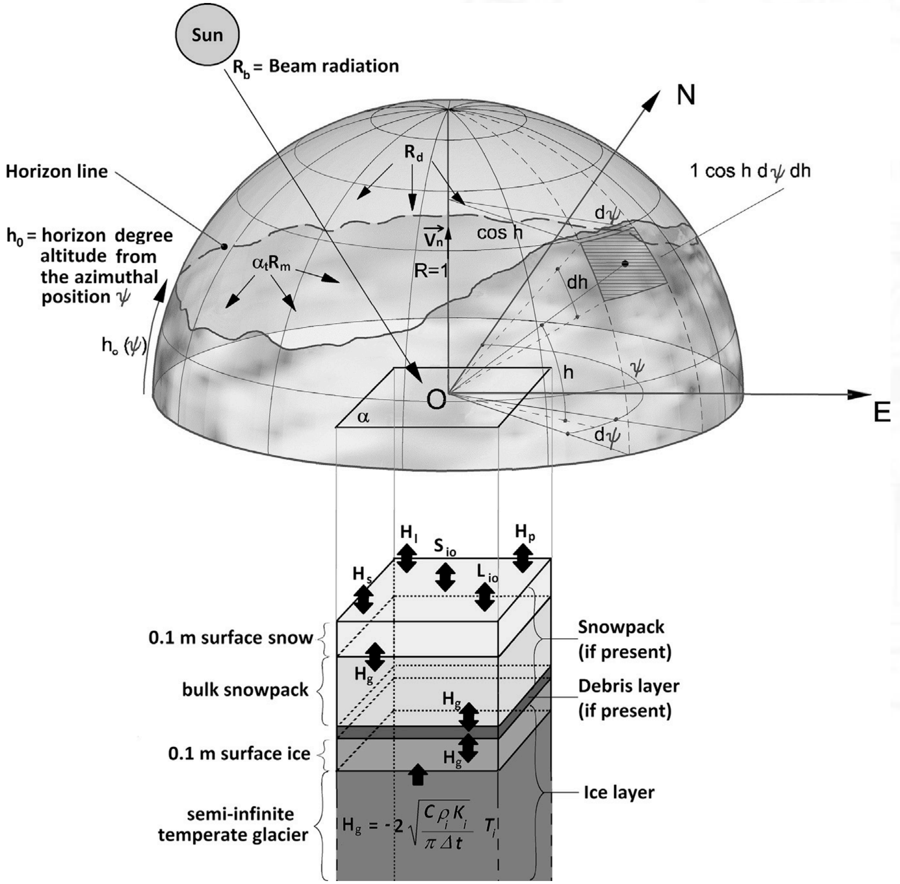
PDSLIM Model Structure

(PDSM Ranzi & Rosso, 1991 for snow; Ranzi et al., 2010 + ice; Grossi et al., 2013 + CC projections of glacier)

The PDSLIM model consist of two main cycles: time and spatial cycle:

In **time cycle**, model executed each hour of the day within a spatial cycle that calculates the individual components of the energy balance on each cell of the area of interest considered.
The energy available for glacierized surface is calculated by

$$H_m + H_c = S_{io} + L_{io} + H_l + H_s + H_p + H_g$$



Here unit of all terms are W/m^2
H_m: energy available for melt,
H_c: Internal Energy of the snow or ice layer,
S_{io}: net shortwave radiation,
L_{io}: net longwave radiation,
H_l: latent heat,
H_s: sensible heat,
H_p: advective heat from precipitation,
H_g: Conductive heat at the bottom side of the snow or ice layer

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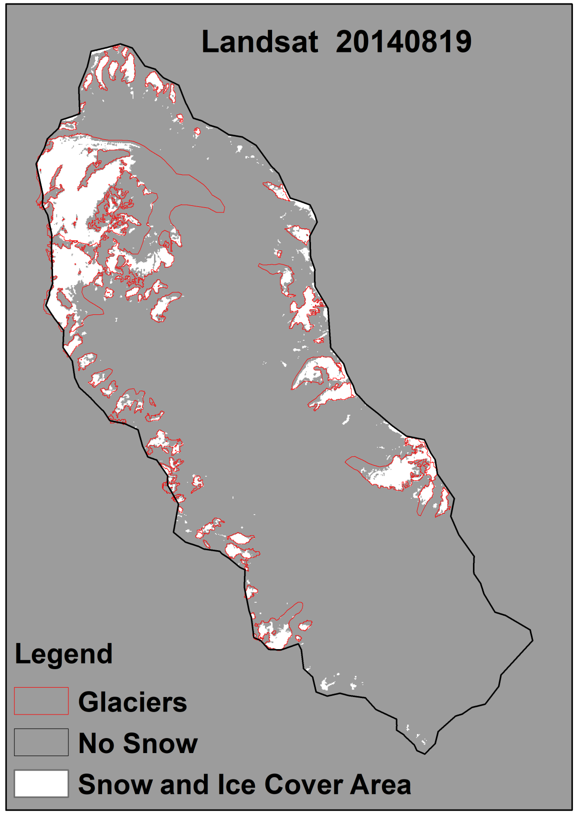
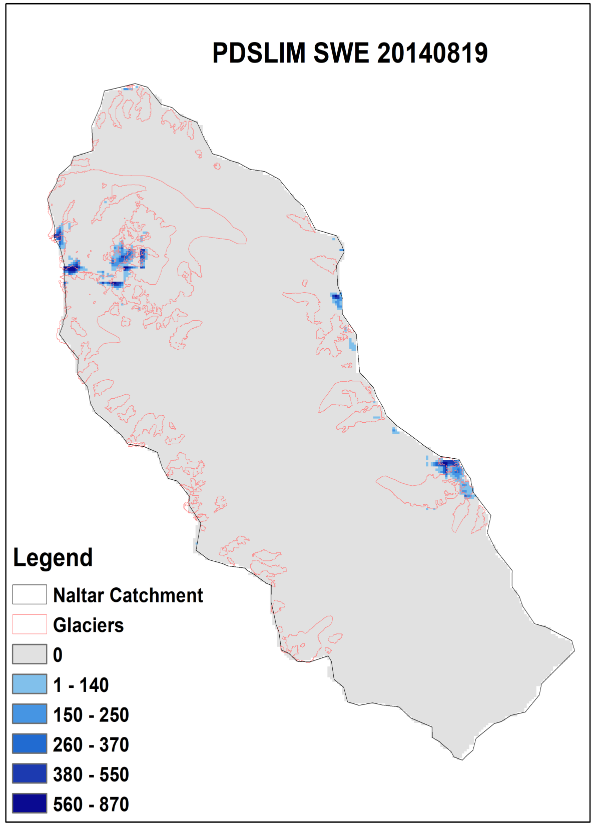
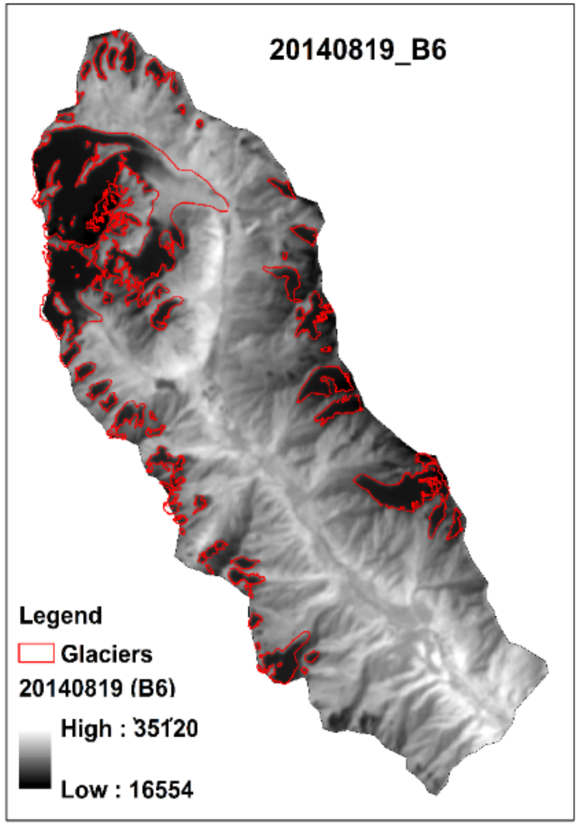
Results of simulation of Snow Cover Area depletion curves 2014







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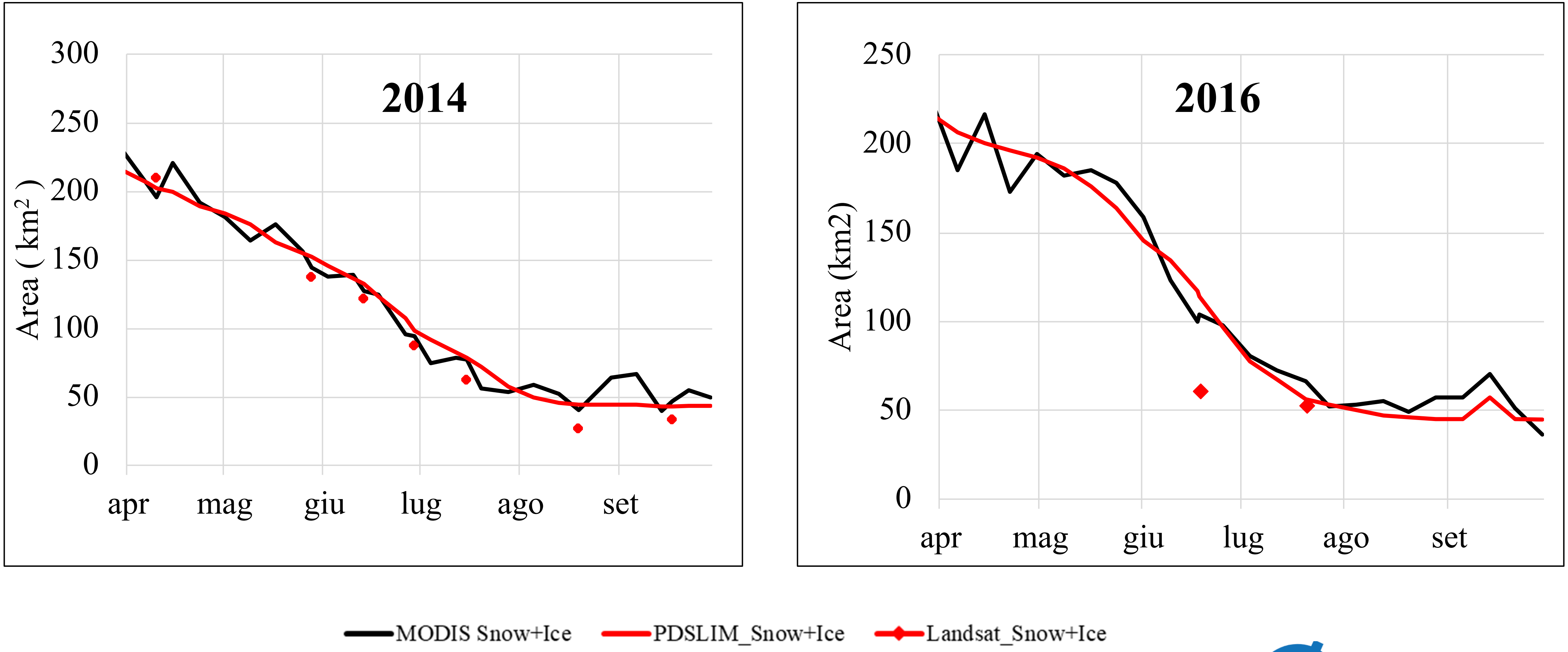
Results of simulation of Snow Cover Area depletion curves 2014 and 2016



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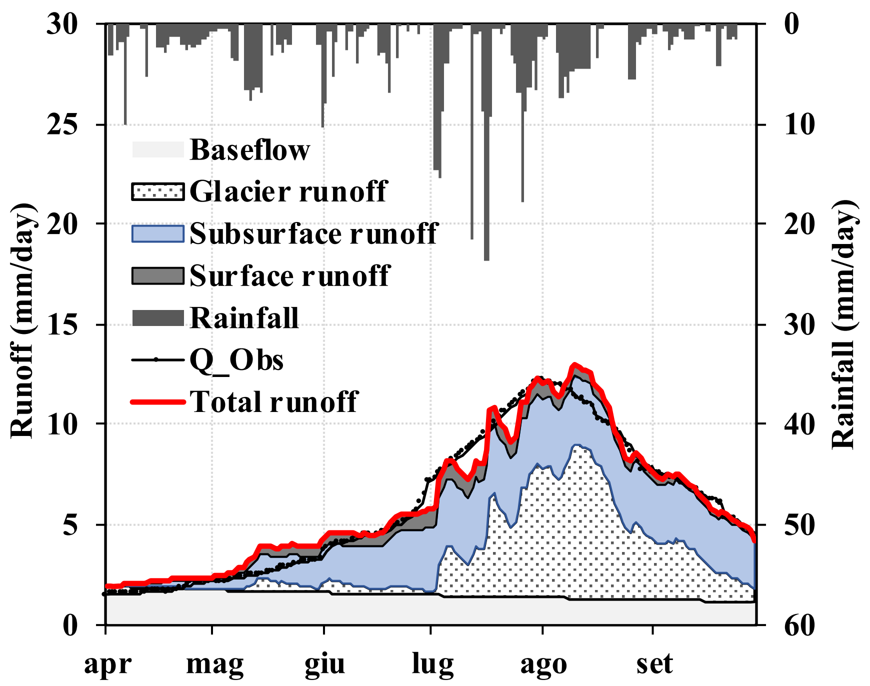
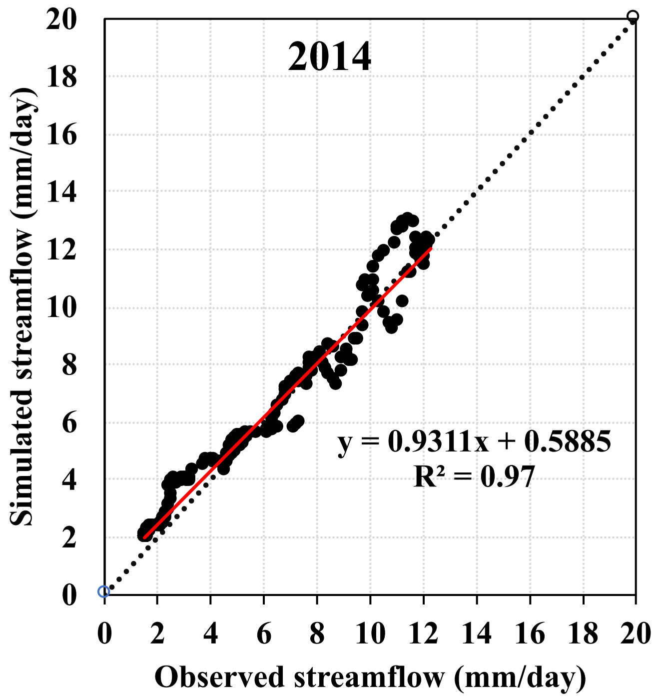
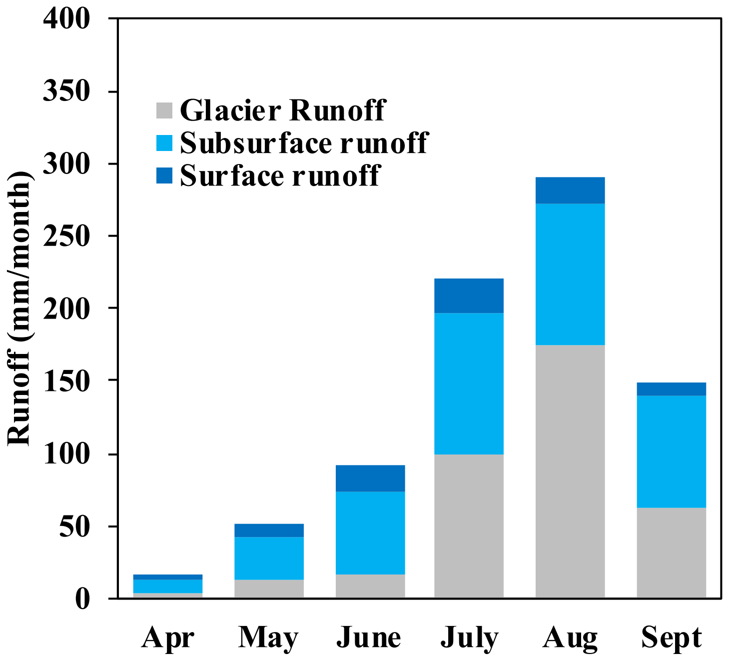
Results of simulation of Snow Cover Area depletion

Year	NSE	ME (km^2)	%Bias	MAPE(%)	RMSE (km^2)	R^2
2006	0.95	3.46	-1.50	13.43	13.38	0.96
2008	0.96	8.66	5.11	10.48	11.98	0.97
2009	0.98	1.62	0.99	7.58	7.83	0.98
2010	0.95	4.59	2.88	6.14	11.52	0.96
2011	0.97	2.83	4.27	10.02	9.96	0.98
2012	0.96	-0.90	-1.93	11.44	12.56	0.97
2014	0.96	-13.07	1.46	9.92	12.15	0.97
2016	0.95	5.44	1.74	8.42	11.31	0.97

Comparison of observed and simulated discharge at Naltar outlet for 2014 with a conceptual linear reservoirs cascade model. NSE 8-year average is 0.87 and 0.88 for calibration and validation







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Mean mass balance for the control period, 2050 and 2090

Year	AAR Acc Area Ratio	Mean MB	2050_4.5	2050_8.5
2006	3%	-1772		
2008	3%	-1712		
2009	4%	-1341		
2010	22%	-1094		
2011	16%	-1454		
2012	11%	-1607		
2014	11%	-1600		
2016	17%	-1158		
Mean	**7%**	**-1468**	**-2862**	**-4228**
		Δ MB (mm)=	**-1262**	**-2628**

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Conclusions

- ✓ The results exhibited satisfactory performance of the distributed energy-balance model against satellite-based snow cover area for all simulated years.
- ✓ Runoff simulations revealed good agreement with observed daily discharge obtained with NSE of 0.87 and 0.88 for calibration and validation period.
- ✓ From the actual (-1500 mm) and projected mass balance (-2900 mm by 2050_4.5; -4200 mm 2050_8.5) estimates and the MODIS+LANDSAT satellite images it appears that also in the Naltar catchment glaciers are going to retreat fast indicating an exception to the ‘Karakoram anomaly’.