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Supplement of

Future snow changes and their impact on the upstream runoff in Salween

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Supplemental methodology:

Bias correction methodology for future scenario meteorological data

Using the delta method to correct the future monthly data of GCM needs to calculate the monthly correction factor that is the differences and fraction between monthly mean of historical observations and the monthly mean of GCM historical simulations (1995-2014). The correction factor is then multiplied or added to the future simulated data of the GCM for the corresponding month (Gleick et al., 1986; Hay et al., 2000). The calculation formula is as follows,

$$T_{fut,cor} = T_{fut,GCM} + \left(\overline{T}_{his,obs} - \overline{T}_{his,GCM,}\right) \quad (1)$$

$$P_{fut,\mathrm{cor}} = P_{fut,GCM} \times \left(\frac{\overline{p}_{his,obs}}{\overline{P}_{his,GCM}}\right) \quad (2)$$

Where $T_{fut,cor}$ is the bias-corrected GCM future air temperature, near-surface air pressure, long-wave radiation and short-wave radiation for the 2021-2100; $P_{fut,cor}$ is the bias-corrected GCM future precipitation, wind speed, and specific humidity for the 2021–2100; $\overline{T}_{his,obs}$ and $\overline{p}_{his,obs}$ is the monthly mean of the observation of historical period (1995–2014); $\overline{T}_{his,GCM}$ and $\overline{P}_{his,GCM}$ is the monthly mean of the GCM simulation of historical period (1995–2014).

Table S1. Trends of the precipitation and temperature in the different periods (near-term, mid-term, and long-term for 2021-2040, 2041-2060, and 2081-2100, respectively) under the CMIP6 scenarios of SSP126 and SSP585.

SSP	Reference		Near-term		Mid-term		Long-term		1995-2100	
	T	P	T	P	T	P	T	P	T	P
SSP126	0.05*	-0.58*	0.02*	1.87*	0.01*	0.19	-0.003*	0.10	0.02*	0.50*
SSP585	0.05*	-0.90*	0.05*	0.95*	0.07*	1.22*	0.07*	3.75*	0.07*	2.78*

‘*’ $p < 0.05$

Table S2. Future changes of temperature and precipitation in the near-term, mid-term and long-term relative to the reference period (1995-2014) for different general circulation models under the CMIP6 scenarios of SSP126 and SSP585.

SSP	GCM	Near term		Mid-term		Long term	
		T (°C)	P (%)	T (°C)	P (%)	T (°C)	P (%)
SSP126	GFDL-ESM4	1.1	1.5	1.3	1.4	1.5	2.9
	IPSL-CM6A-LR	1.5	5.9	2.0	6.5	2.1	8.3
	MPI-ESM1-2-HR	1.2	1.3	1.6	1.1	1.4	2.7
	MRI-ESM2-0	1.5	9.9	1.9	9.5	1.9	8.3
	Ensemble-mean	1.3	4.6	1.7	4.6	1.7	5.6

	GFDL-ESM4	1.1	-4.7	2.2	-0.2	4.3	9.4
	MPI-ESM1-2-HR	1.7	2.4	3.1	4.2	9.1	59.2
SSP585	IPSL-CM6A-LR	1.4	-1.2	2.1	2.6	4.7	13.4
	MRI-ESM2-0	1.8	8.8	3.0	12.2	5.6	26.0
	Ensemble-mean	1.5	1.3	2.6	4.7	5.9	27

Table S3. Trends and relative changes of annual mean FSCA (fraction of snow cover area) of different periods at different elevation bands under SSP126 and SSP585

SSP	Scale	All	Reference		Near term		Mid-term		Long term	
		trend	trend	%	trend	change%	trend	change%	trend	change
SSP126	Basin mean	-0.040*	-0.695*	50.7	0.040	5.0	0.010	-9.0	0.070	-2.8
	4000m <	-0.001*	0.013	0.7	-0.004	-25.7	0.001	-39.7	0	-30.3
	4000-4500m	-0.008*	-0.062	5.6	0.023	-3.3	0.010	-22.0	-0.010	-11.8
	4500-5000m	-0.005*	-0.597*	25.2	0.003	10.1	0.008	-5.3	-0.070	-1.0
	5000-5500m	-0.020*	-0.067	18.3	-0.003	0.1	-0.040	-9.7	0.030	-6.3
	>5500m	0	0	0.8	0	-2.8	-0.002*	-7.2	0.001*	-5.5
SSP585	Basin mean	-0.420*	-0.695*	50.7	-0.210*	-4.8	-0.692*	-21.4	-0.493*	-64.1
	4000m <	-0.006*	0.013	0.7	0	-37.7	-0.005	-57.1	0.001	-86.1
	4000-4500m	-0.050*	-0.062	5.6	-0.020	-17.8	-0.064*	-38.8	-0.031	-76.6
	4500-5000m	-0.230*	-0.597*	25.2	-0.122*	-1.5	-0.362*	-20.3	-0.271*	-66.6
	5000-5500m	-0.130*	-0.067	18.3	-0.073*	-5.8	-0.244*	-18.2	-0.193*	-57.6
	>5500m	-0.003*	0	0.8	-0.001	-5.0	-0.005*	-10.9	-0.006*	-33.9

'*' $p < 0.05$

Table S4. Relative changes of future seasonal FSCA in different periods under the SSP126 and SSP585.

Item	Period	Spring		Summer		Autumn		Winter	
		SSP126	SSP585	SSP126	SSP585	SSP126	SSP585	SSP126	SSP858
Relative Change (%)	Near term	-0.2	-9.1	22.2	-10.0	14.5	-4.8	-6.9	-16.1
	Mid-term	-9.7	-19.0	3.8	-21.8	0.7	-17.7	-15.9	-27.3
	Long term	-15.7	-56.6	10.2	-75.8	4.7	-68.4	-13.4	-64.9

Table S5. Relative changes of future annual total runoff, total melt and snow runoff in different periods under SSP126 and SSP585

SSP	Period	Total runoff(mm)	Relative change (%)	Total melt(mm)	Relative change (%)	Snow runoff(mm)	Relative change (%)
SSP126	Near term	344.6	1.1	185.9	-14.2	66.6	11.3
	Mid-term	376.5	10.4	175.7	-19.0	47.7	-20.3
	Long term	357.1	4.7	179.8	-17.1	68.9	15.0
SSP585	Near term	345.8	1.4	180.5	-16.7	54.2	-9.5
	Mid-term	418.9	22.9	168.0	-22.5	41.1	-31.3
	Long term	723.9	112.3	123.5	-43.0	14.9	-75.2
Reference		341.0		216.8		59.9	

Table S6. Proportion of future multi-year averaged annual and seasonal snow runoff to total runoff in different periods under the SSP126 and SSP585. TR, total runoff; SR, snow runoff.

SSP	Period	SR/TR (%)	Spring (%)	Summer (%)	Autumn (%)	Winter (%)
SSP126	Near term	19.3	1.2	15.6	2.5	0.0
	Mid-term	12.7	1.1	10.1	1.5	0.0
	Long term	19.3	1.3	15.5	2.4	0.0
SSP585	Near term	15.7	1.2	12.6	1.9	0.0
	Mid-term	9.8	1.1	7.6	1.1	0.0
	Long term	2.1	0.4	1.4	0.3	0.0
Reference		17.6	0.8	15.0	1.7	0.0

Table S7. Change and proportion of seasonal snow runoff (SR) to total runoff (TR) comparing to the reference period.

SSP	Period	Spring(mm)			Summer(mm)			Autumn(mm)			Winter(mm)		
		TR	SR	%	TR	SR	%	TR	SR	%	TR	SR	%
SSP126	Near term	15.7	4.1	25.9	214.4	53.9	25.1	106.1	8.7	8.5	11.6	0.01	0.09
	Mid-term	17.8	4.3	24.2	232.4	37.9	16.3	113.2	5.5	4.9	13.1	0.01	0.08
	Long term	18.4	4.7	25.6	216.5	55.4	25.3	106.3	8.7	8.2	12.9	0.01	0.09
SSP585	Near term	18.1	4.1	22.5	210.7	43.7	20.7	105.3	6.4	6.1	12.6	0.007	0.05
	Mid-term	19.9	4.8	22	257.6	31.8	12.3	125.2	4.5	3.6	14.5	0.01	0.1
	Long term	38.5	2.9	7.6	433.0	9.9	2.3	228.8	2.1	0.9	23.6	0.02	0.09
Reference		20.1	2.9	14.3	199.8	51.1	25.6	104.7	5.9	5.6	16.4	0.01	0.05

Table S8. Change and proportion of seasonal snow runoff (SR) to total snowmelt (TM) comparing to the reference period.

SSP	Period	Spring(mm)			Summer(mm)			Autumn(mm)			Winter(mm)		
		TM	SR	%	TM	SR	%	TM	SR	%	TM	SR	%
SSP126	Near term	13.1	4.1	31	144.2	53.9	37.4	28.6	8.7	30.5	0.1	0.01	13.2
	Mid-term	14.5	4.3	29.7	134.0	37.9	28.3	27.2	5.5	20.3	0.1	0.01	9.6
	Long term	13.4	4.7	35.2	139.1	55.4	39.8	27.2	8.7	32.1	0.1	0.01	12.4
SSP585	Near term	14.1	4.1	28.9	139.6	43.7	31.3	26.8	6.4	23.9	0.1	0.007	8
	Mid-term	17.8	4.8	26.8	125.7	31.8	25.3	24.3	4.5	18.7	0.2	0.014	9.1
	Long term	25.2	2.9	11.6	77.7	9.8	12.7	20.1	2.0	10.3	0.6	0.02	3.6
Reference		11.4	2.9	25.1	170.7	51.1	29.9	34.6	5.9	17.1	0.1	0.01	12.3

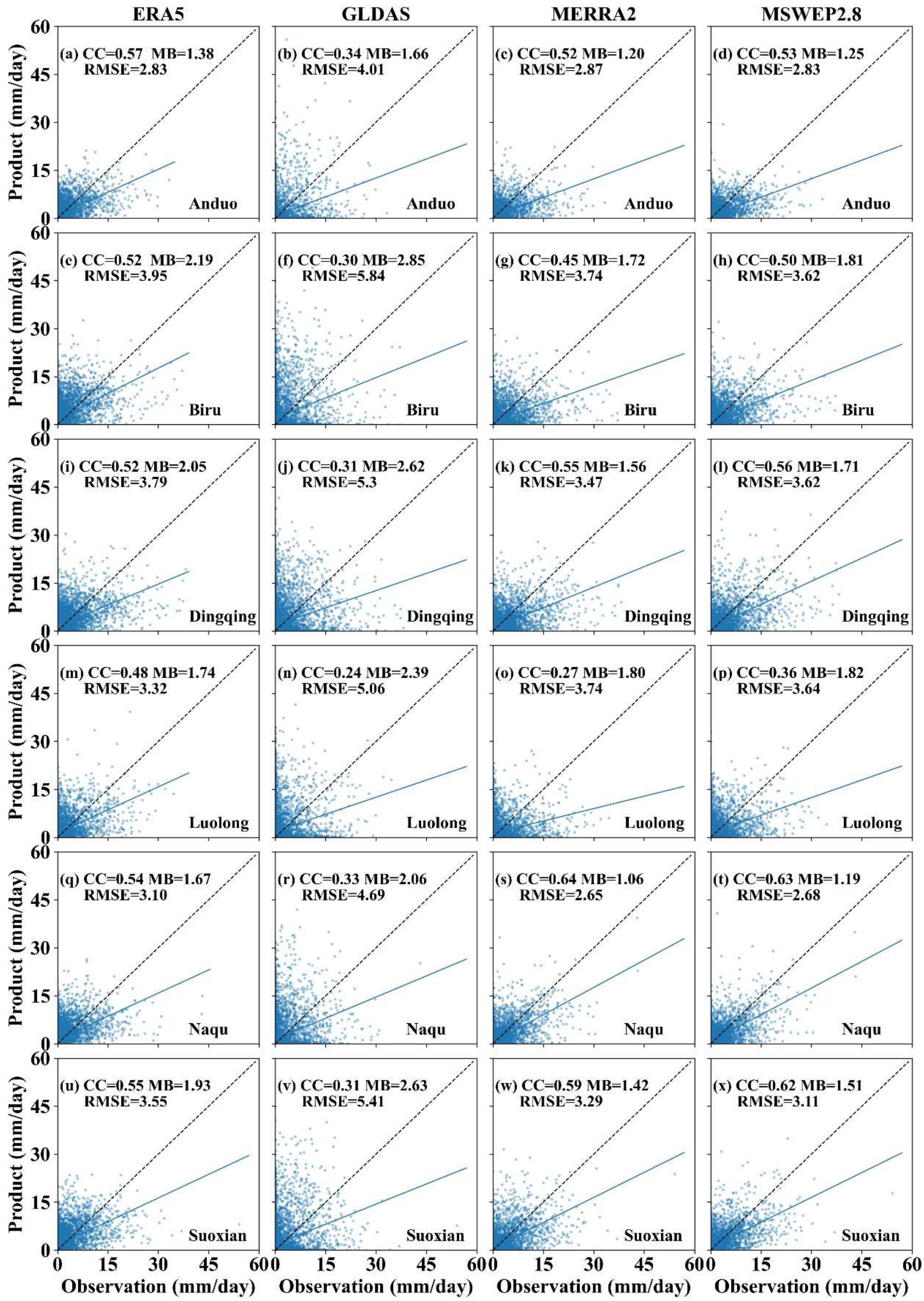

Figure. S1 Comparison of the daily precipitation values between the gauge observation and different operational global products during 2000-2019. The results of ERA5, GLDAS, MERRA2, and MSWEP2.8 are given from the first to the fourth column.

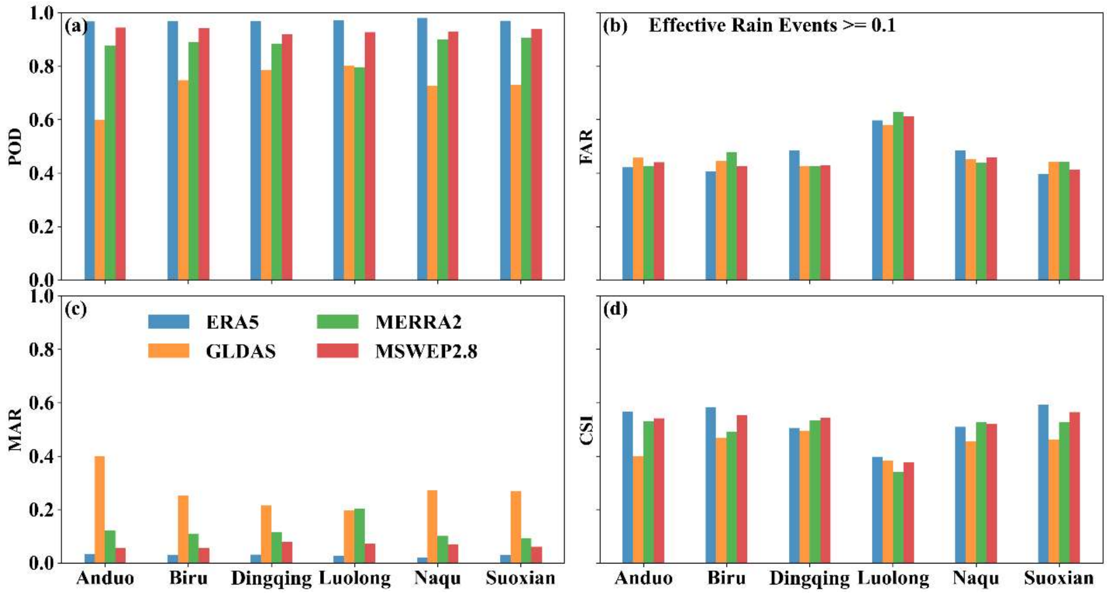

Figure. S2 Evaluation of capturing ability of different global operational products to precipitation events. Effective precipitation is defined as daily precipitation greater than or equal to 0.1 mm. (a) POD (probability of detection); (b) FAR (false alarm ratio); (c) MAR (missing alarm rate), and (d) CSI (critical success index).

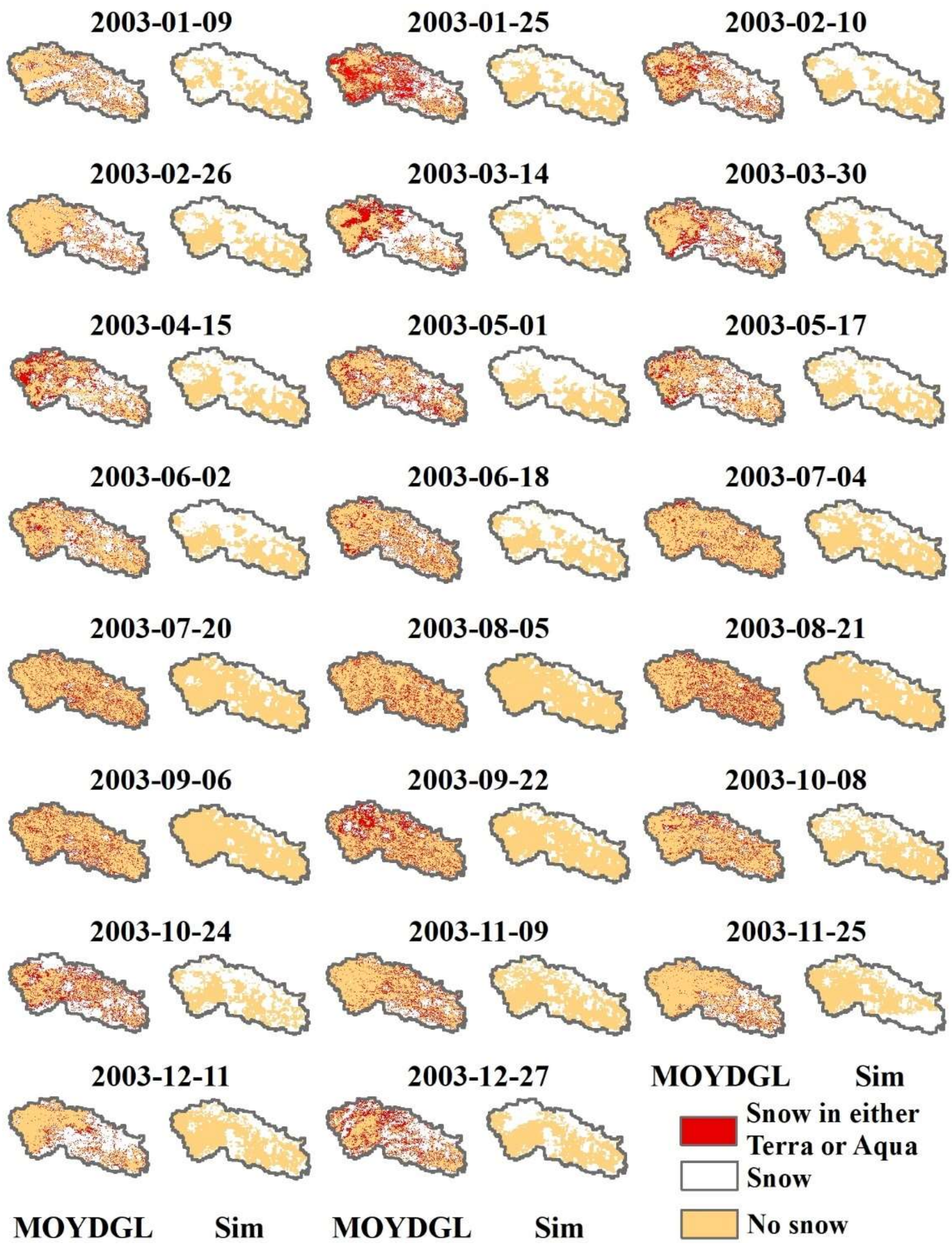

Figure. S3 Comparison of the MODIS 8-day snow cover product (MOYDGL06*) and the simulated 8-day snow cover in the US basin in 2003. The time interval is 16 days.

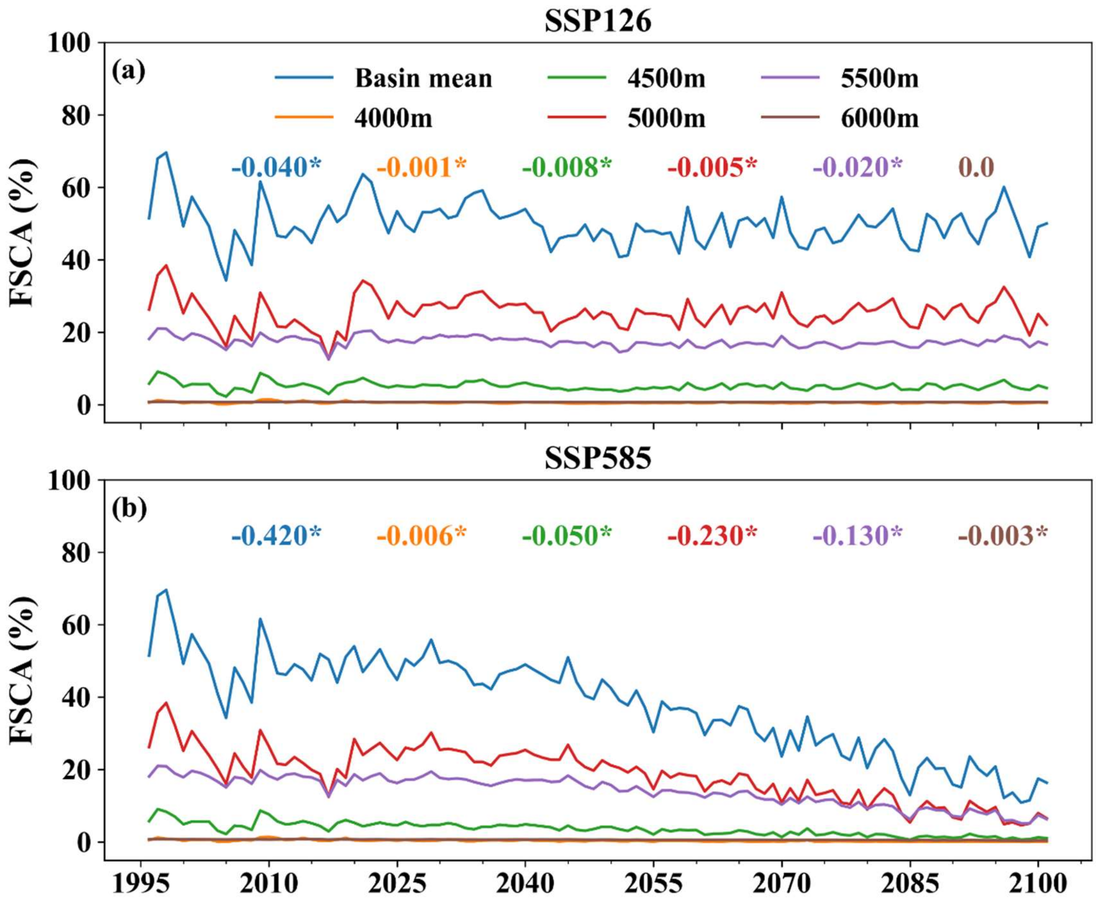

Figure. S4 Trends of annual mean FSCA for different scale under the CIMP6 scenarios of SSP126 and SSP585 from 1995 to 2100 in the US basin, the number with color is trend for the line with same color, and the "*" indicates a significant trend ($p < 0.05$).

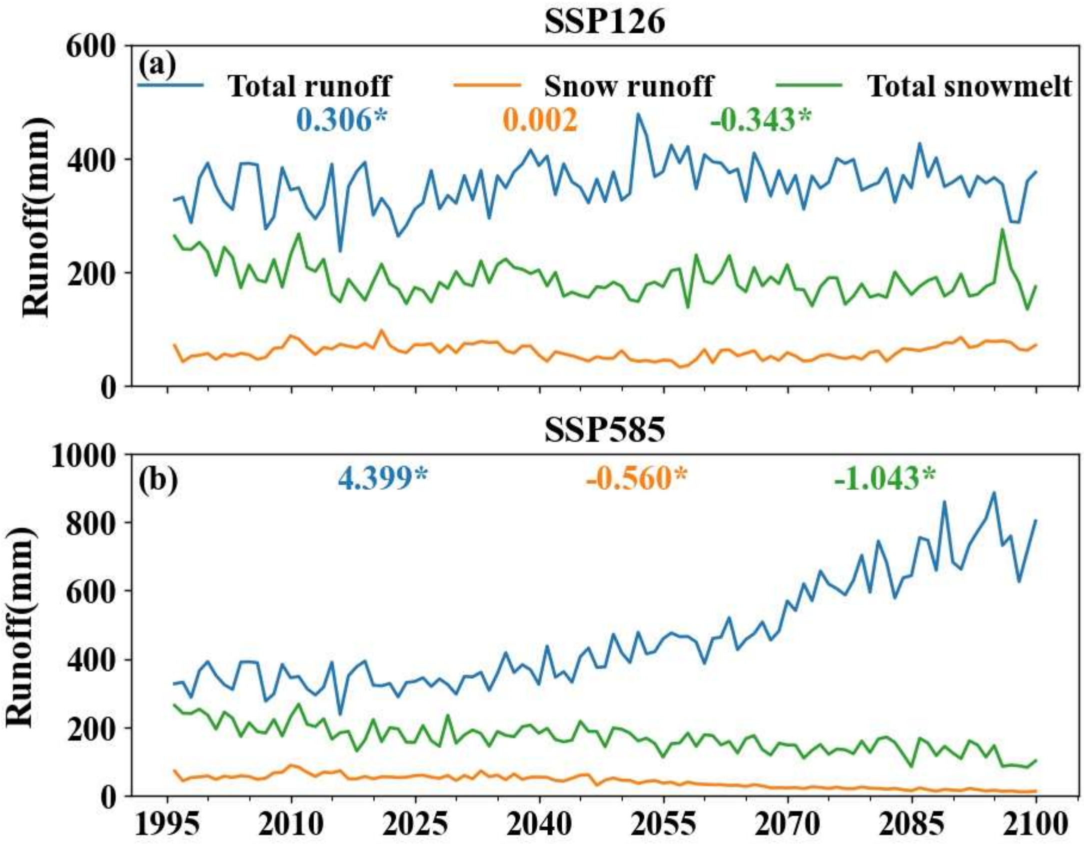

Figure. S5 Trends of annual total runoff, snow runoff and total snowmelt under SSP126 and SSP585 from 1995 to 2100 in the US basin, the number with color is trend for the line with same color, and the "*" indicates a significant trend ($p < 0.05$).

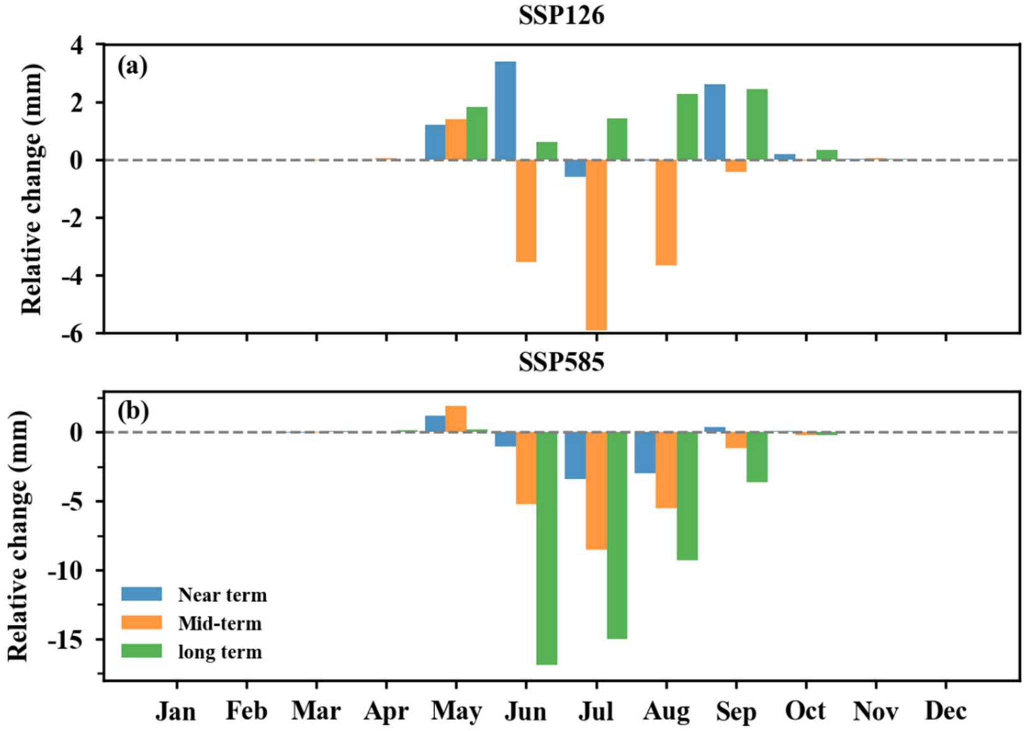

Figure. S6 Relative changes of snow runoff in different periods under SSP126 and SSP585 comparing to the reference period (1995-2014) in the US basin.

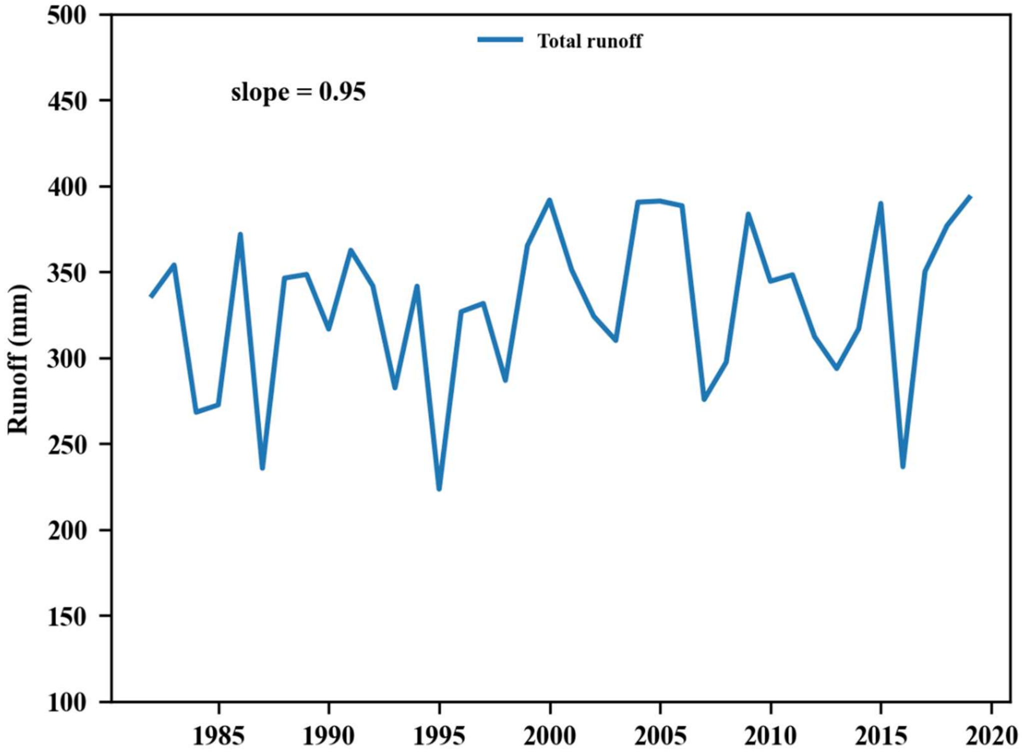

Figure. S7 Changes of total runoff in the historical period (1981-2018) in the UB basin.

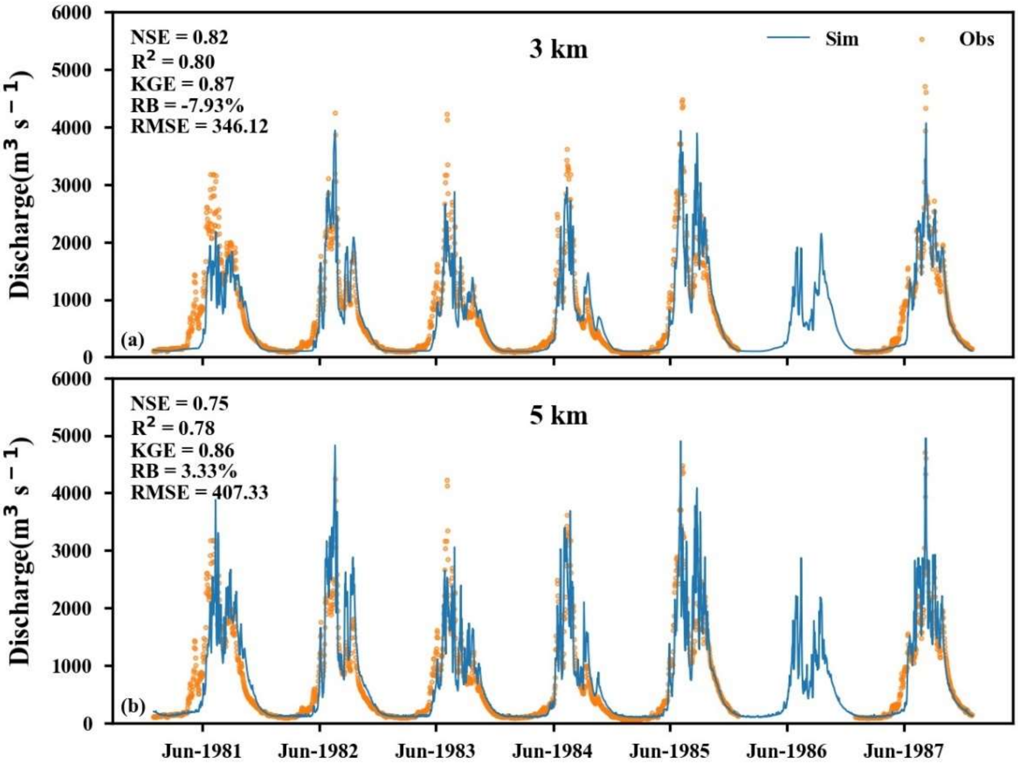

Figure. S8 Simulated and observed (a) 3 km and (b) 5km daily discharges at Jiayuqiao (JYQ) station from 1981 to 1987. The calibration and validation periods were 1981–1983 and 1984–1987, respectively.

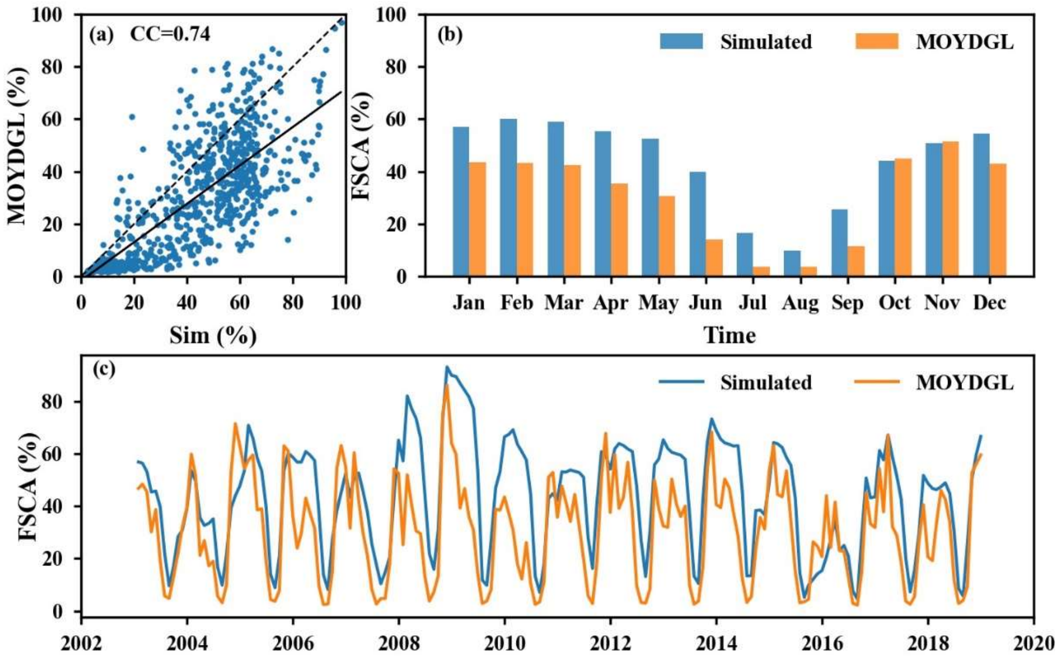

Figure. S9 Comparison of the simulated 3km fraction of the snow cover area (FSCA) and the MOYDGL06* time series in the USR basin. (a) 8-day FSCA; (b) multi-year mean monthly FSCA; and (c) variations in the monthly FSCA during 2003–2018.

Reference

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