Supporting Information for

Regional difference in runoff regimes and changes in the Yarlung Zangbo river basin

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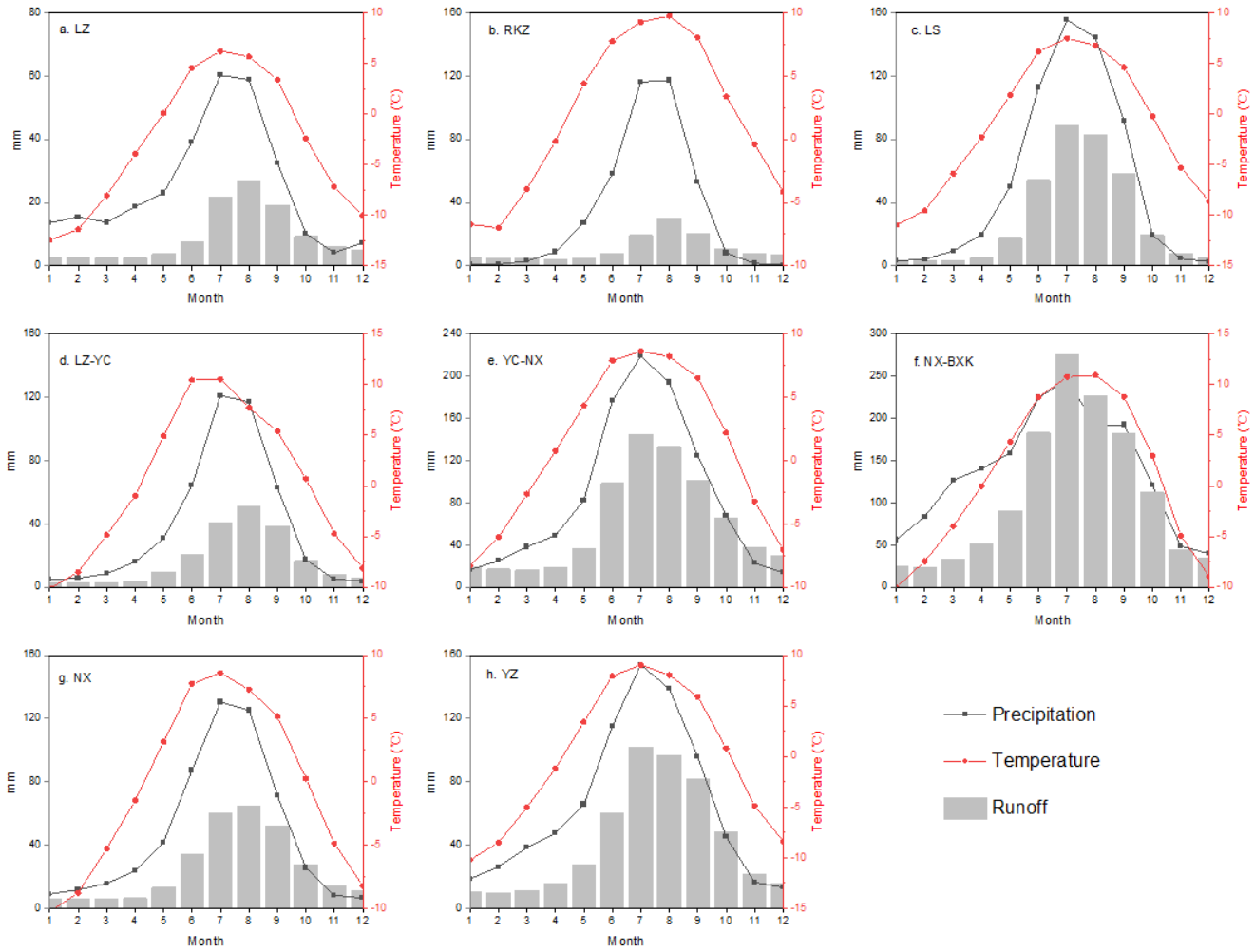
Text S1. Teleconnection Indices

The monthly vertical integrated atmospheric moisture fluxes derived from the ERA5 data and ten teleconnection indices for 1971–2020 were used to examine the factors contributing to runoff changes in the YZ basin. These indices included the Arctic Oscillation (AO, https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtml), East Asian Summer Monsoon Index (EASM, http://data.tpdc.ac.cn/), El Niño/Southern Oscillation (ENSO, https://www.psl.noaa.gov/enso/mei), North Atlantic Oscillation (NAO, https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtml), Atlantic Multidecadal Oscillation (AMO, http://www.psl.noaa.gov/data/timeseries/AMO/), Pacific Decadal Oscillation (PDO, http://research.jisao.washington.edu/data_sets/), Indian Ocean Dipole (IOD, https://www.jamstec.go.jp/aplinfo/sintexf/iod/dipole_mode_index.html), South Asian Summer Monsoon Index (SASMI, http://lijianping.cn/dct/page/65576), Indian Summer Monsoon Index (ISM, http://apdrc.soest.hawaii.edu/projects/monsoon/), and the westerly index (WI). The WI is defined as the proportion of days in a month with the prevailing wind direction from the region between 30^{o} E−70^{o} E and 35^{o} N−50^{o} N based on ERA5 estimates.



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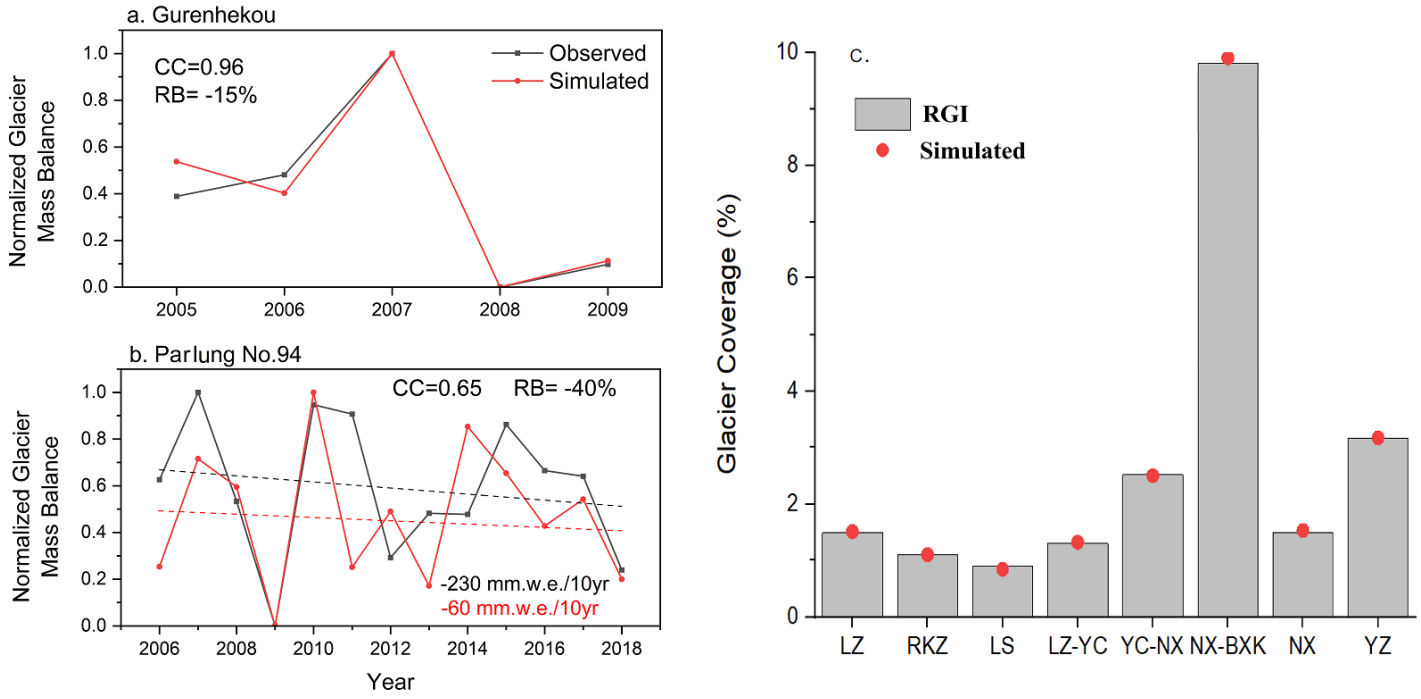

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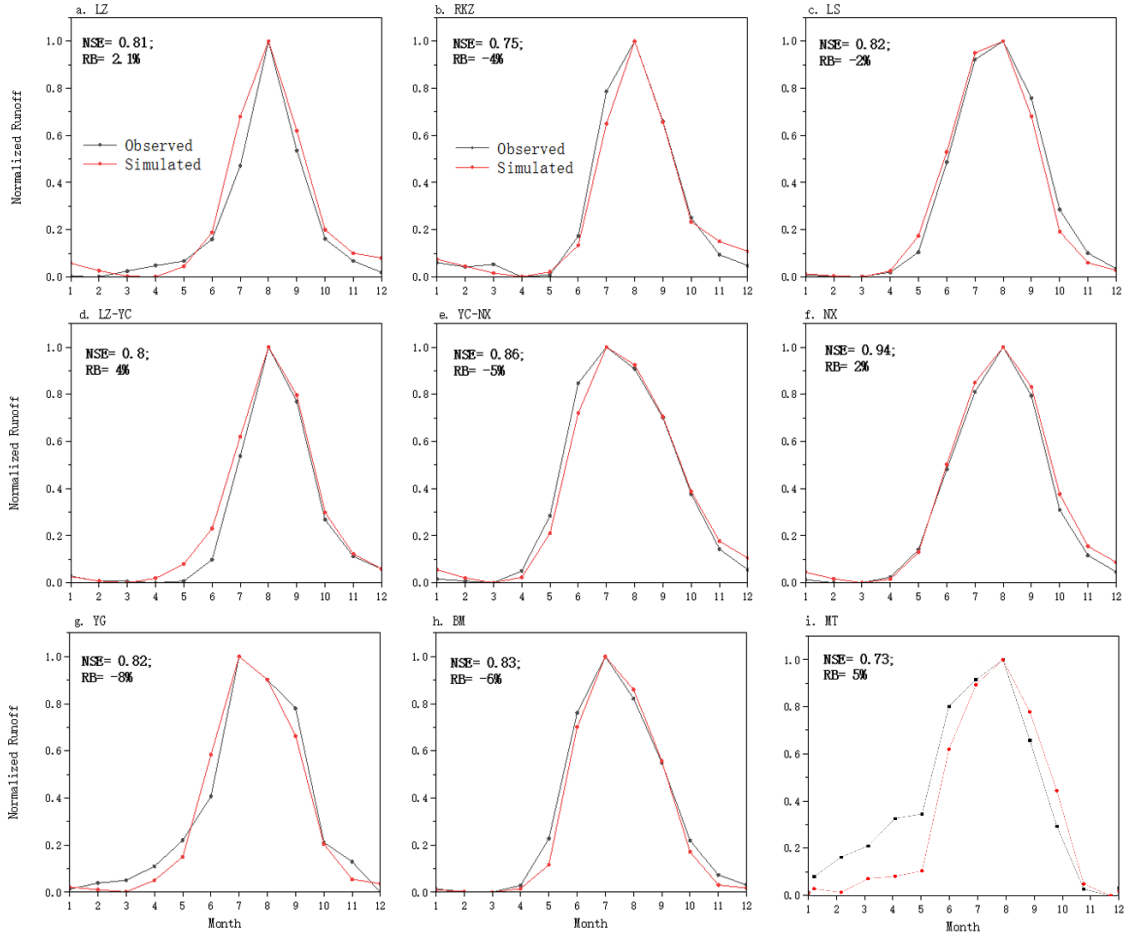

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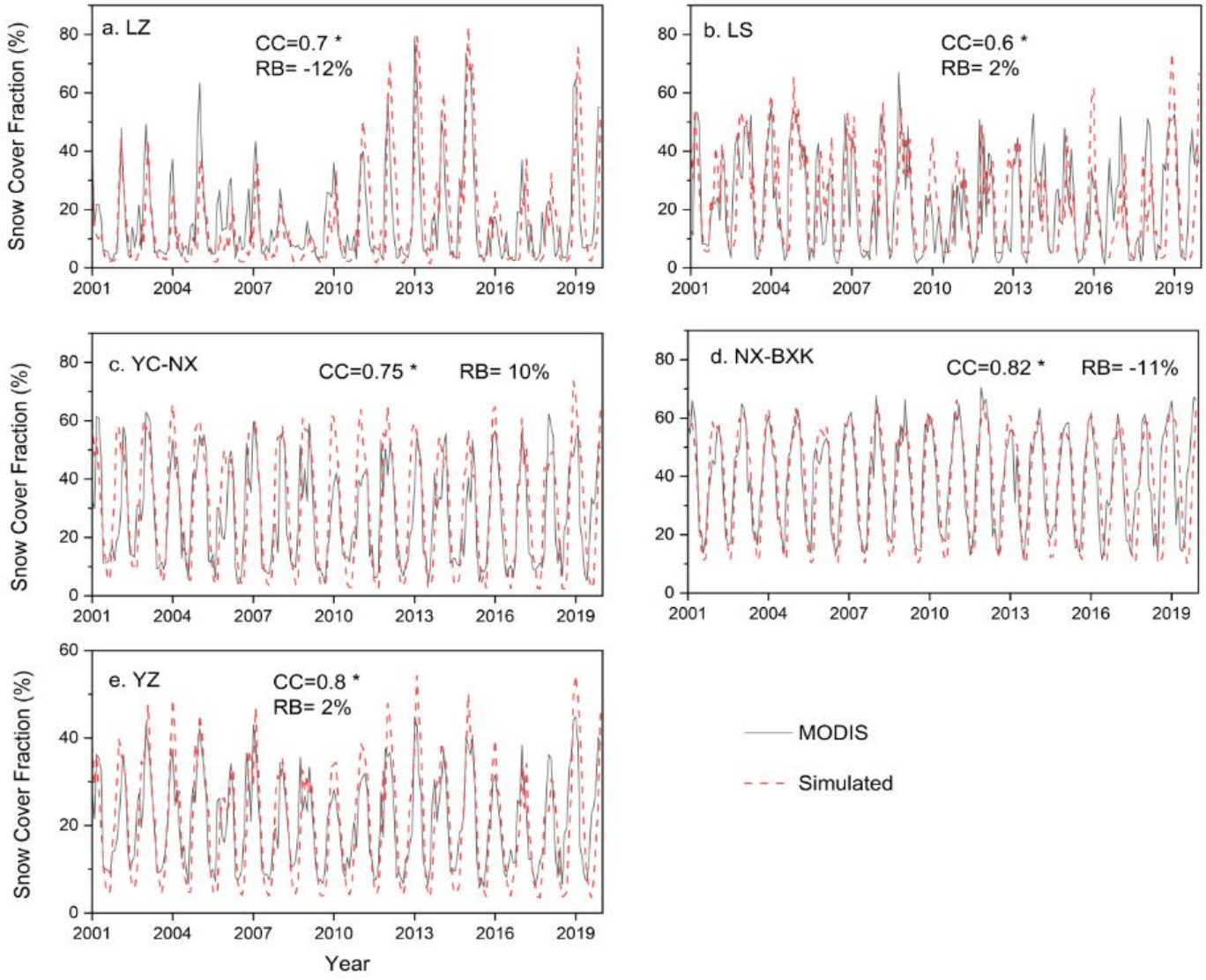

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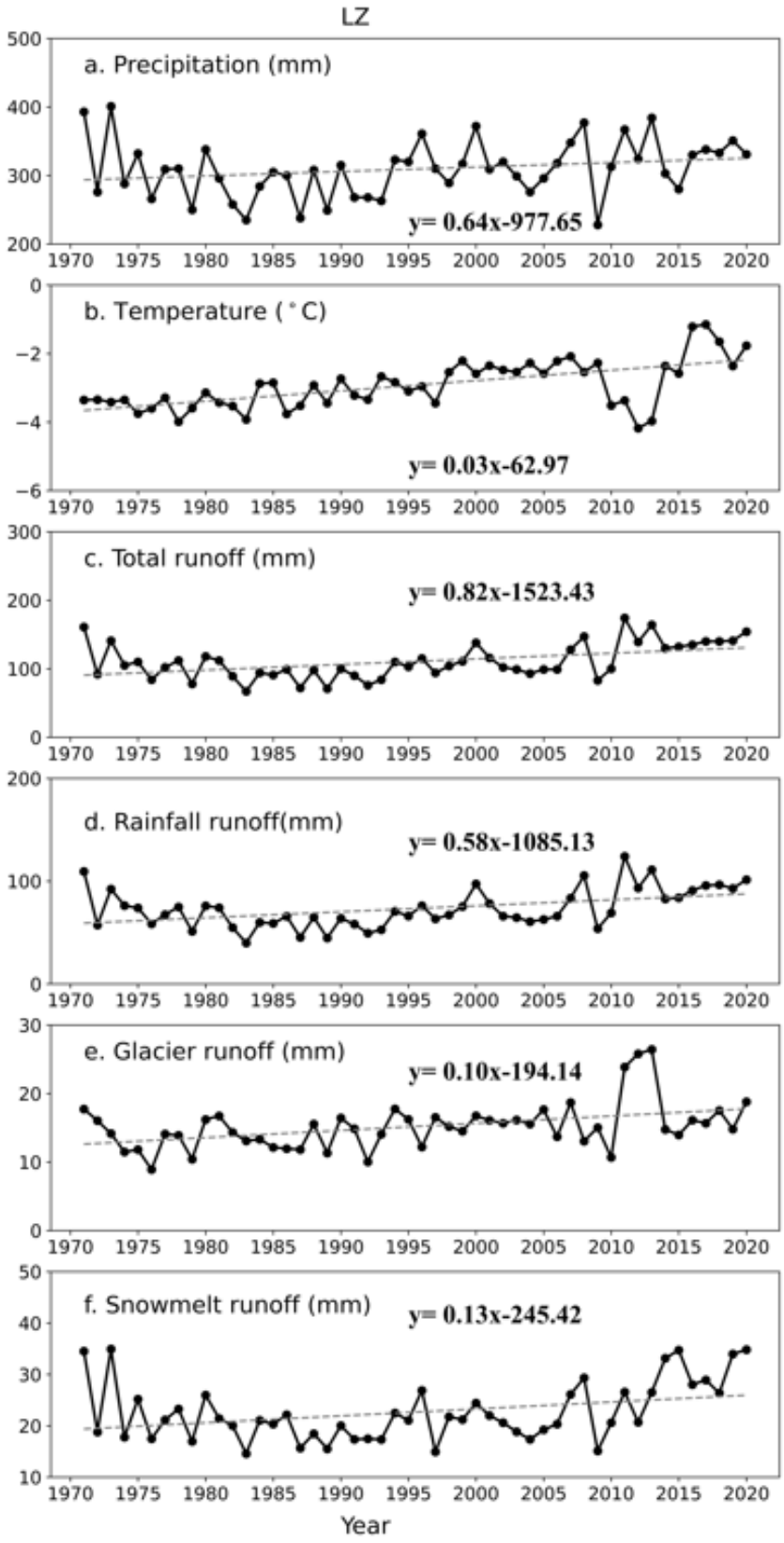
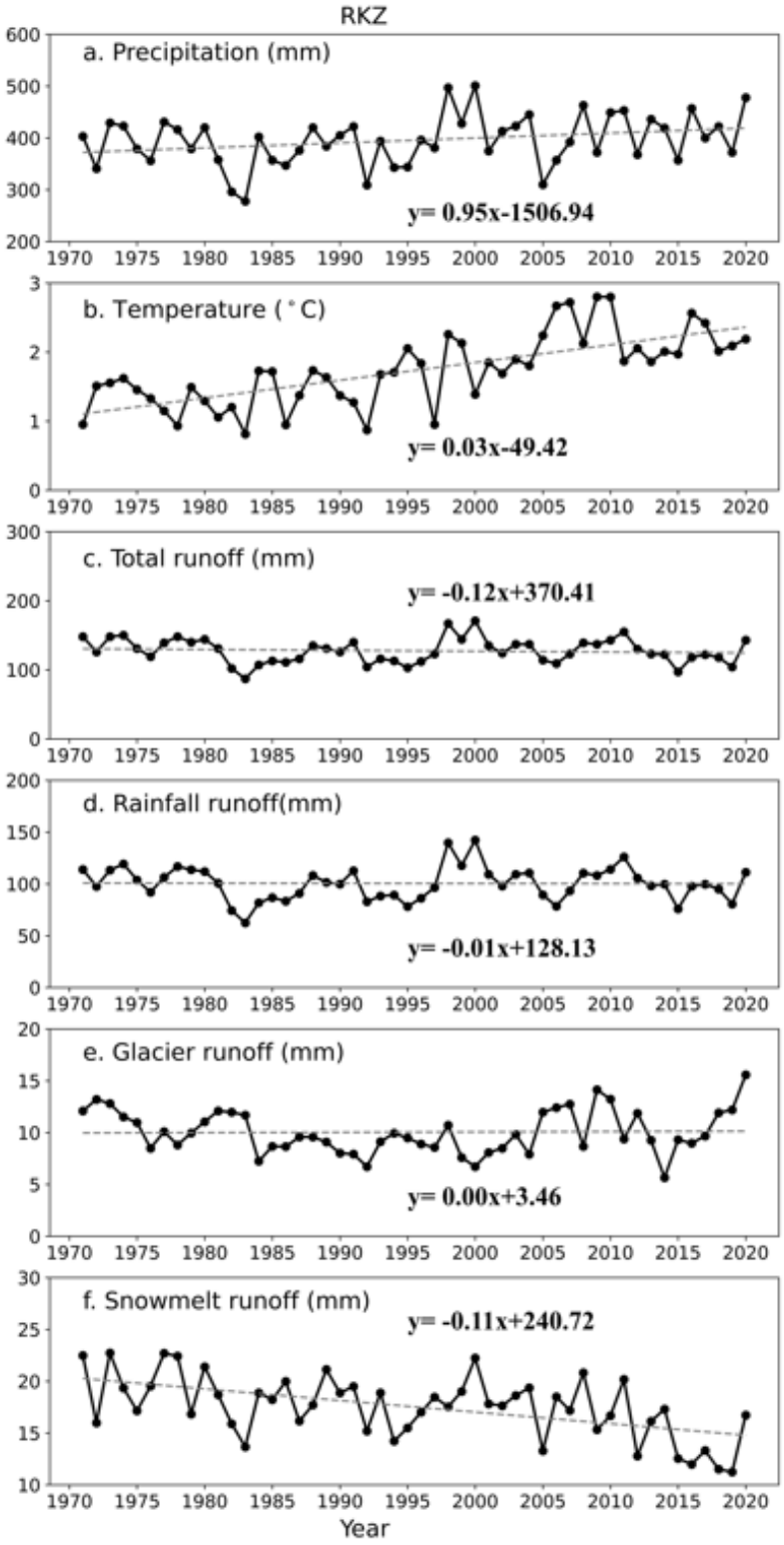


Figure S5. Annual variations in precipitation, temperature, total runoff, and the three runoff components (rainfall, glacier, and snowmelt runoff) in the LZ sub-basin for 1971–2020, respectively.



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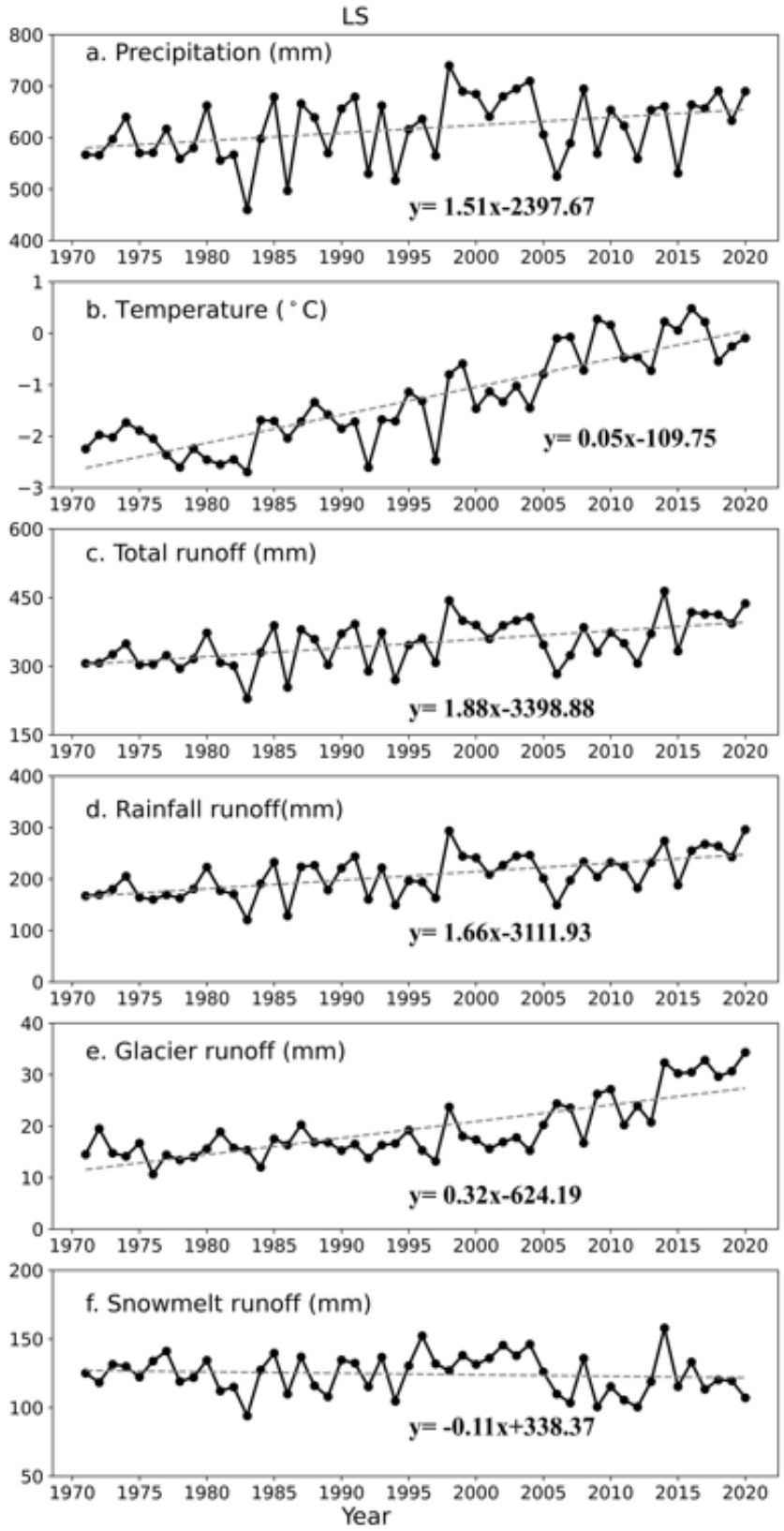

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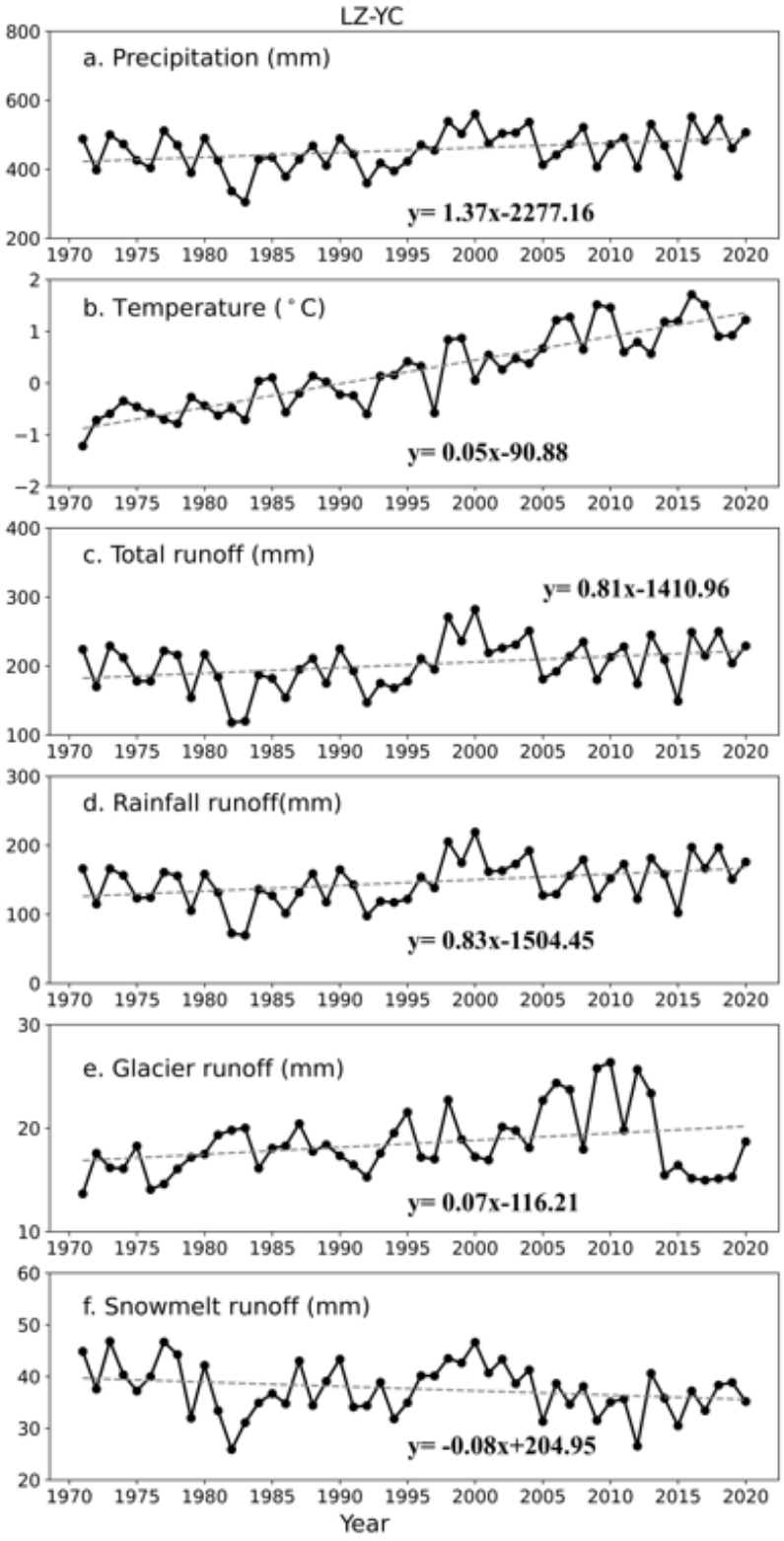

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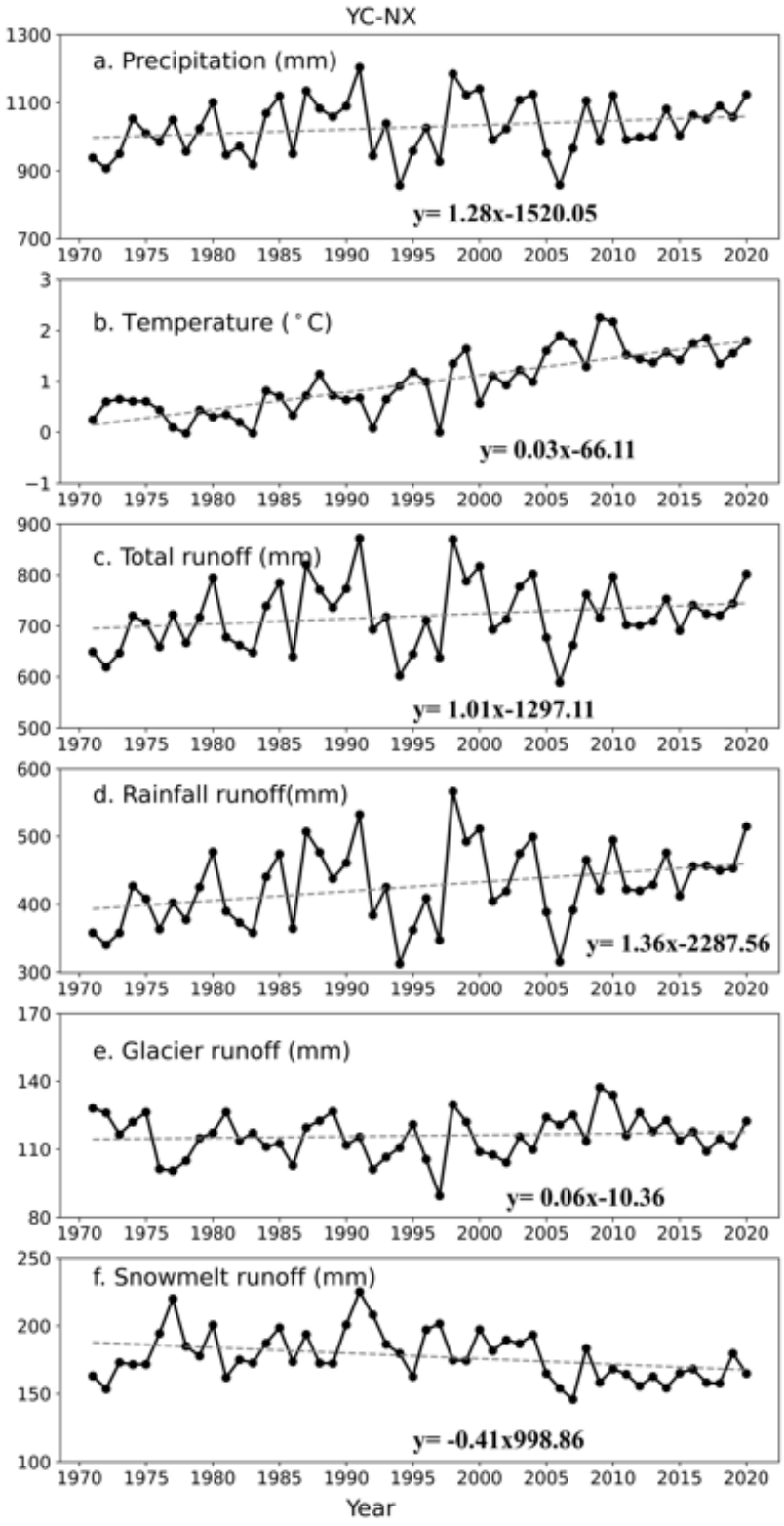

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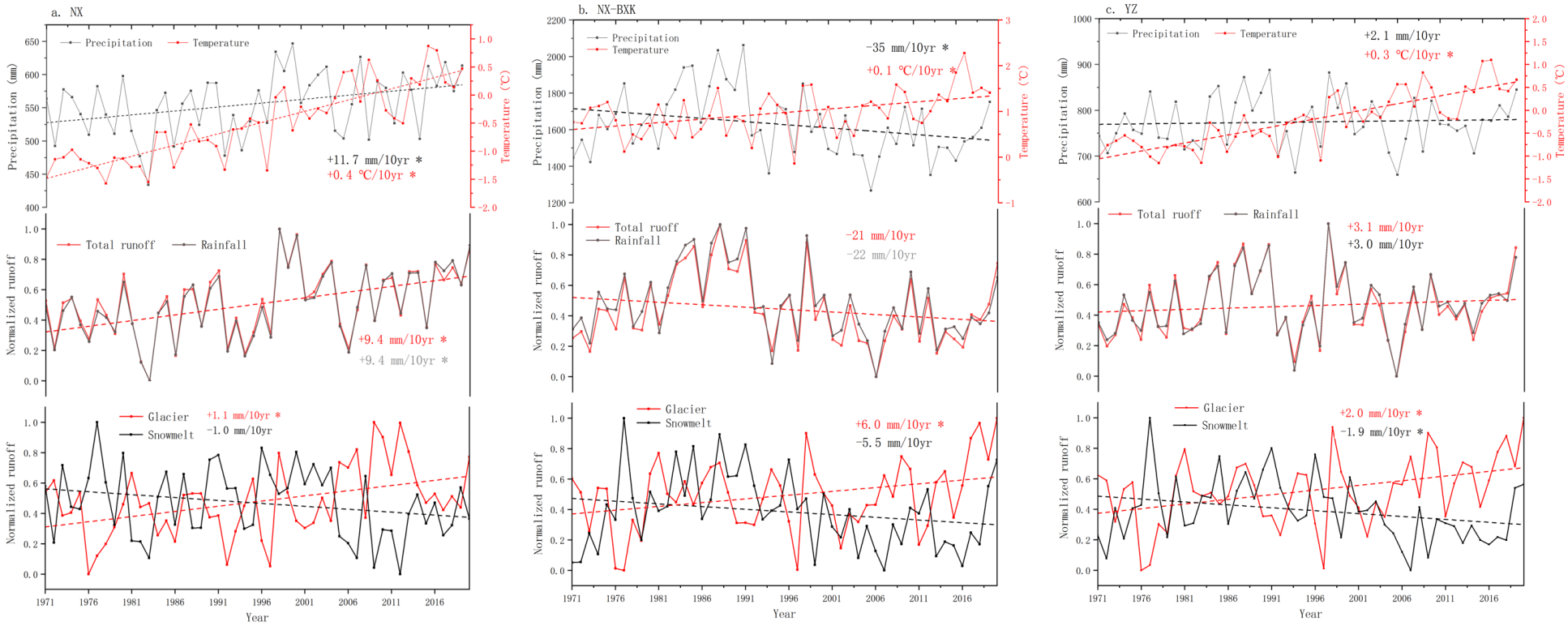

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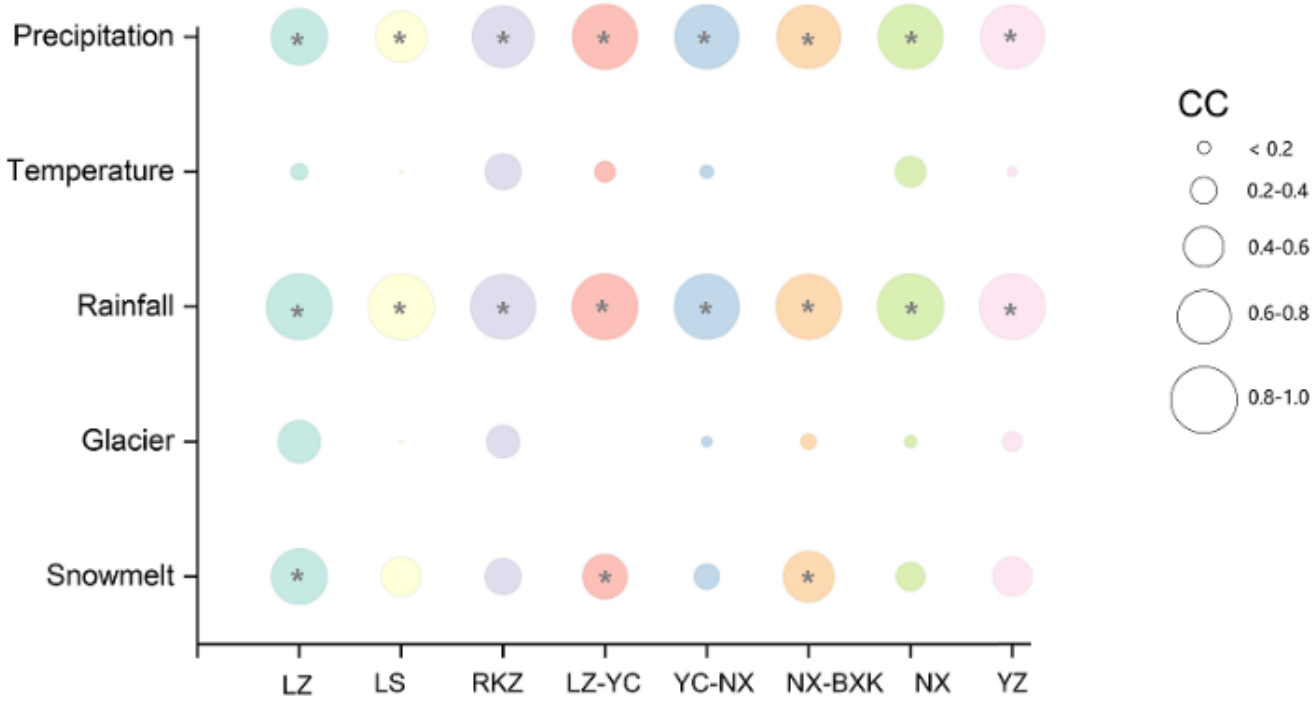

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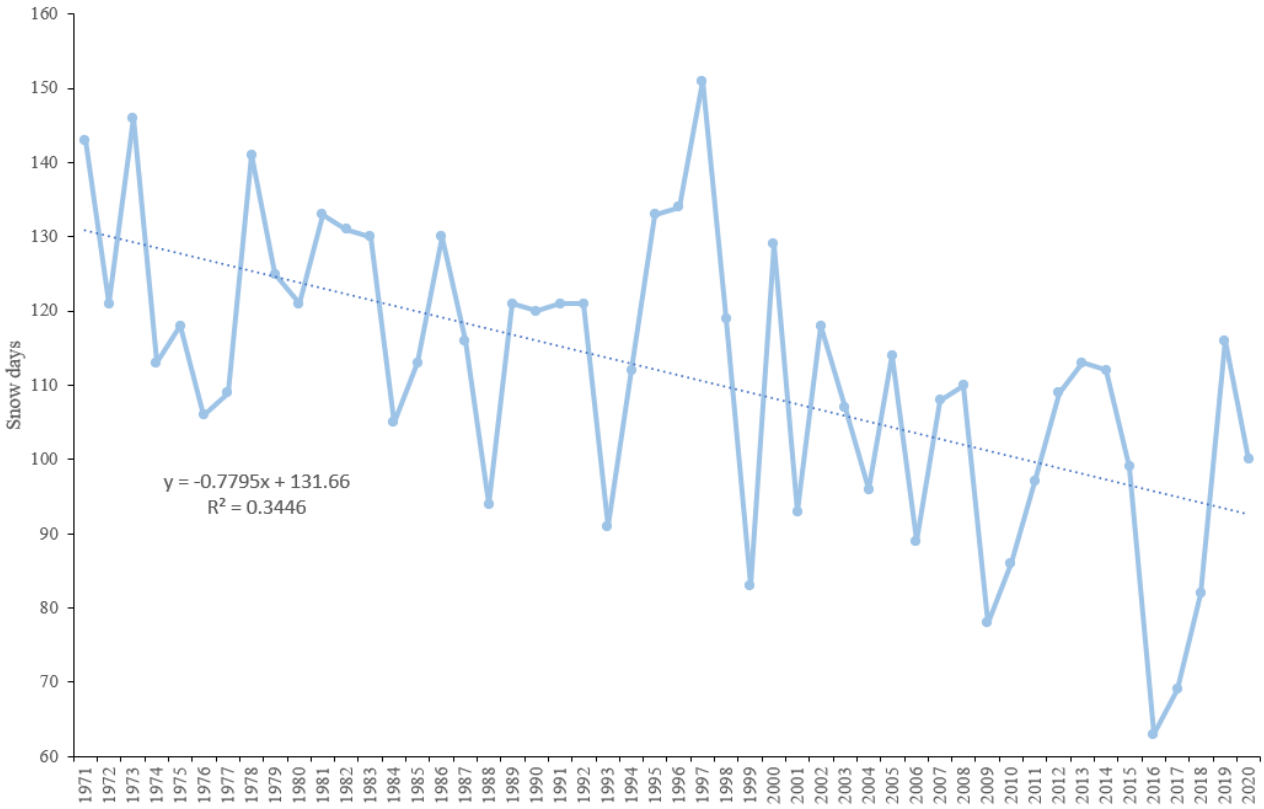

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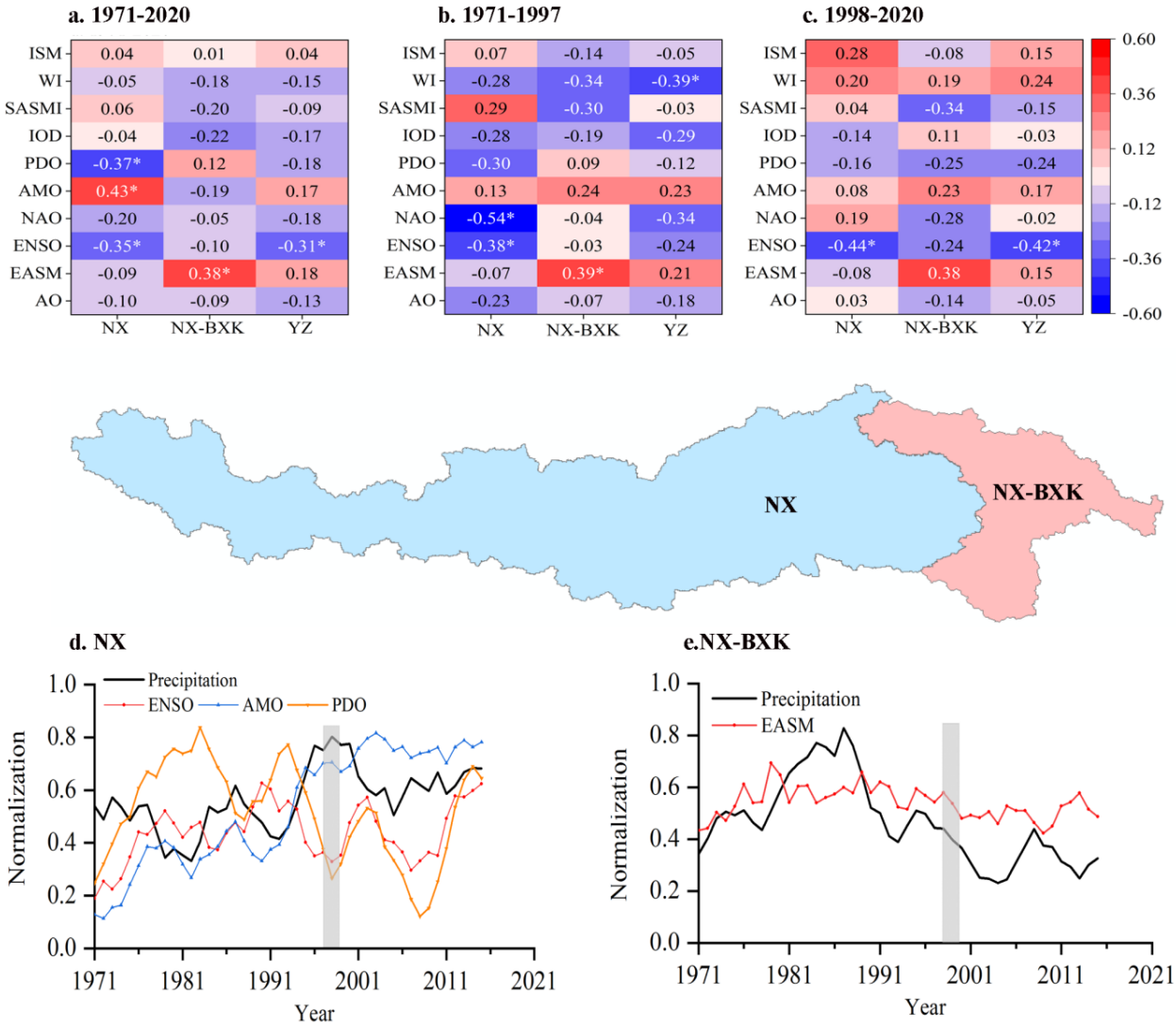

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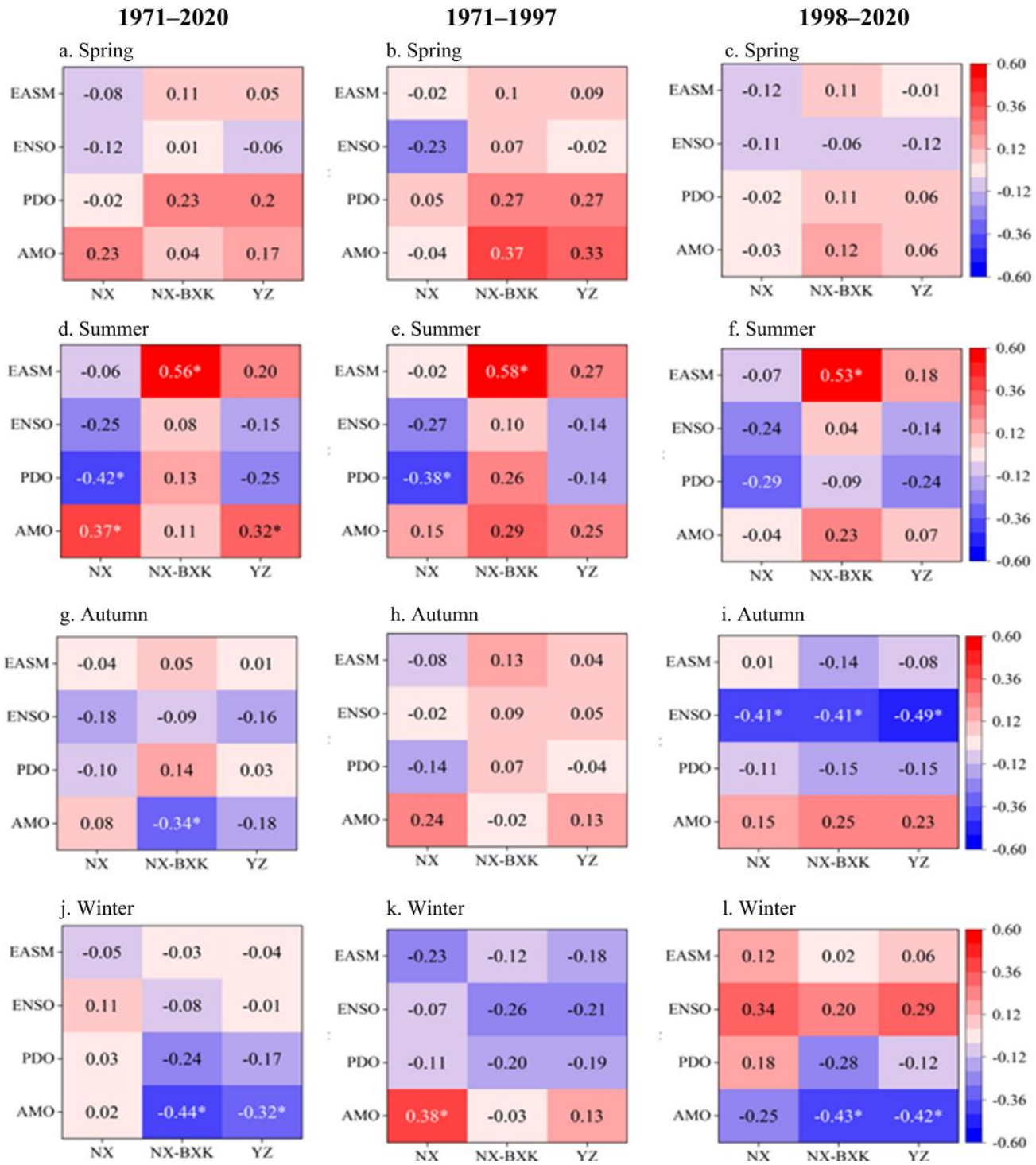

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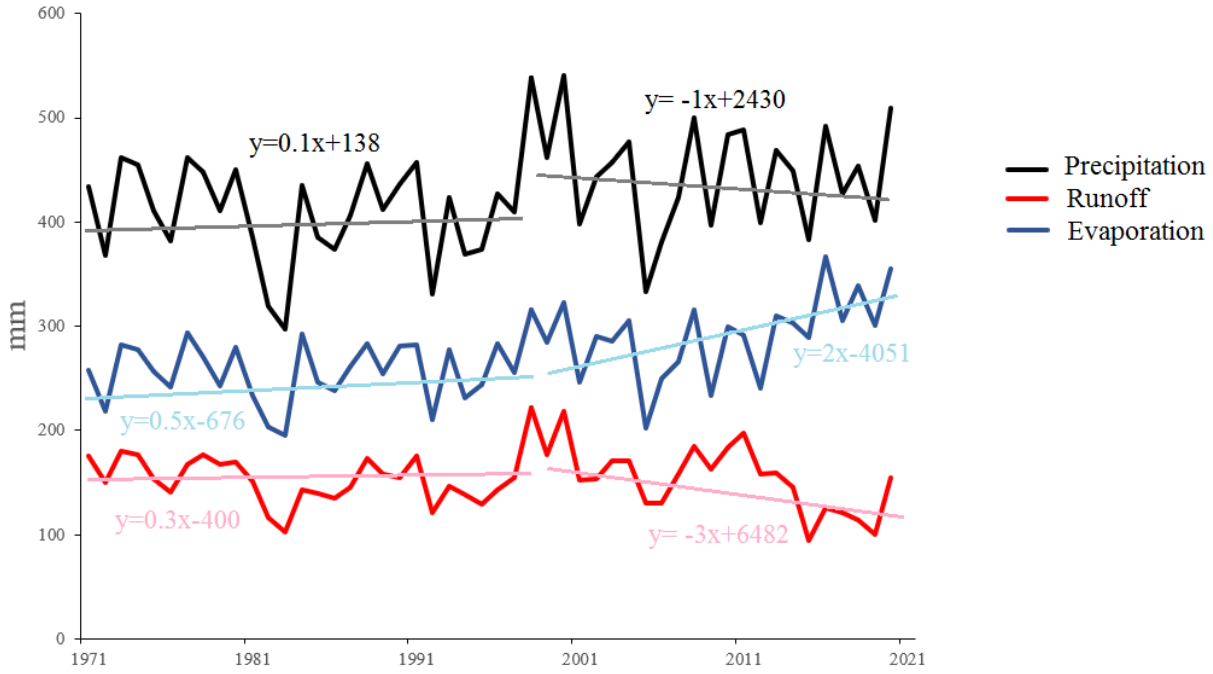

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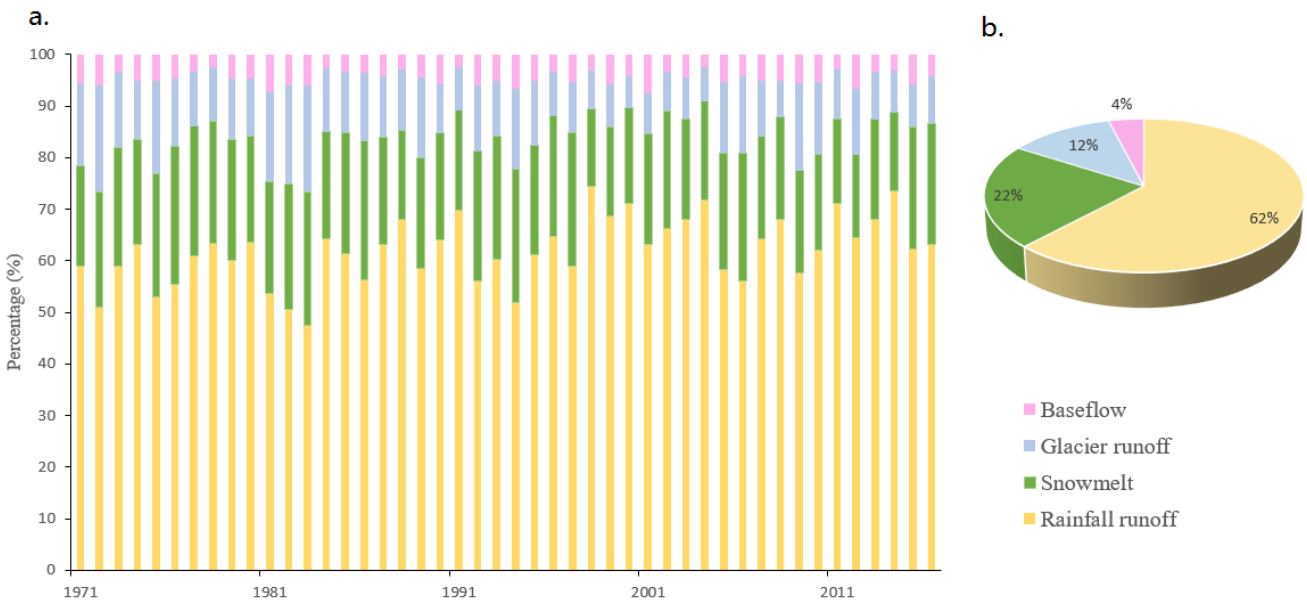

Figure S16. (a) Annual variations in contribution of rainfall runoff, snowmelt, glacier runoff and baseflow to total runoff in the YZ basin for 1971–2020. (b) Mean annual contribution of rainfall runoff, snowmelt, glacier runoff and baseflow to total runoff.

Table S1. List of data used in this study for the VIC-Glacier model validation.

Data	Source	Resolution	Station name	Period
Observed runoff	Tibetan Hydrological Bureaus	Site, Monthly	Lhatse (LZ)	1971–2015
			Shigatse (RKZ)	1971–2015
			Lhasa (LS)	1971–2015
			Yangcun (YC)	1971–2015
			Nuxia (NX)	1971–2015
			Yigong (YG)	1981–2000
			Bomi (BM)	2004–2013
			Motuo (MT)	2020
Glacier mass balance	Institute of Tibetan Plateau Research, Chinese Academy of Sciences (http://www.tpdc.ac.cn)	Site, Annual	Gurenhekou	2005–2009
		Site, Annual	Parlung No.94	2006–2018
Glacier Inventory	The first Glacier Inventory of China	–	–	1970s−1990s
	Randolph Glacier Inventory (RGI V6.0)	–	–	2000s−2010s
Snow cover fraction	the Moderate Resolution Imaging Spectroradiometer (MODIS)10CM (https://nsidc.org/data)	Site, Annual	Parlung No.94	2006–2018

Table S2. Changes in mean seasonal precipitation (%), temperature (℃), total runoff, and the three components (%), along with their contributions to total runoff (%) in 1998–2020 relative to the period 1971–1997 in the entire YZ basin and its NX and NX-BXK sub-basins.

	Month	Pre	Tem	Total	Glacier	Snow melt	Rainfall	CG	CS	CR
NX	Jan	1.31	1.19	4.83	0	54.4	3.57	0	1.15	-1.18
	Feb	3.01	1.17	4.84	0	35.68	2.99	0	1.62	-1.70
	Mar	-0.88	0.35	9.41	0	50.35	2.65	0	5.09	-5.16
	Apr	6.14	0.85	17.19	0	33.49	4.82	0	5.70	-5.37
	May	17.62	0.4	22	6.56	23.58	25.24	-1.42	0.81	0.61
	Jun	9.08	0.55	10.83	9.3	-2.47	30.16	-0.23	-6.17	6.40
	Jul	15.81	0.44	20.74	8.91	-9.2	37.54	-1.71	-5.92	7.63
	Aug	8.28	0.59	11.36	8.79	-14.35	20.41	-0.34	-4.84	5.18
	Sep	-2.58	0.69	6.63	12.72	-19.89	16.22	0.88	-6.42	5.54
	Oct	6.15	0.7	6.14	20.83	-3.94	8.61	0.93	-2.30	1.37
	Nov	-11.89	1.54	7.05	0	29.92	4.3	0	2.35	-2.30
	Dec	-11.19	2.2	5.74	0	24.49	4.99	0	0.70	-0.71
NX-BXK	Jan	-9.97	0.63	-9.54	0	-4.14	-9.84	0	0.33	-0.33
	Feb	-16.21	0.69	-14.74	0	-18.2	-14.21	0	-0.79	0.77
	Mar	-15.12	-0.1	-18.38	0	-28.89	-13.89	0	-3.87	3.85
	Apr	-11.04	0.16	-19.61	0	-17.26	-21.08	0	1.02	-1.00
	May	3.11	0.09	-13.28	1.65	-5.45	-21.75	0.66	3.10	-3.77
	Jun	-8.35	0.35	-6.32	4.43	-6.08	-9.86	1.54	0.15	-1.68
	Jul	-3.15	0.41	-1.34	11.85	-9.5	-3.06	2.81	-1.90	-0.91
	Aug	5.23	0.34	-3.54	5.02	-21	-3.97	2.76	-2.39	-0.37
	Sep	-20.5	0.57	-5.98	-0.1	-15.41	-7.94	1.69	-0.81	-0.88
	Oct	-10.74	0.46	-16.49	14.12	-22.58	-22.93	6.16	-0.38	-5.78
	Nov	-9.09	0.51	-7.05	0	6.97	-7.85	0	0.64	-0.72
	Dec	-18.61	0.86	-8.29	0	-14.03	-8.09	0	-0.20	0.17
YZ	Jan	-3.19	0.58	-1.01	0	8.3	-1.4	0	0.37	-0.37
	Feb	-5.56	0.58	-2.92	0	-3.37	-2.91	0	-0.04	0.01
	Mar	-6.06	0.14	-4.76	0	-8.45	-3.72	0	-0.74	0.71
	Apr	-2.51	0.38	-5.55	0	-1.92	-8.12	0	1.44	-1.51
	May	5.28	0.18	-1.75	1.8	2.93	-8.11	0.17	2.11	-2.28

Jun	1.01	0.28	0.48	3.25	-1.25	1.43	0.37	-0.85	0.48
Jul	4.88	0.23	3.87	5.81	-5.58	6.96	0.46	-2.14	1.68
Aug	3.88	0.29	2.51	3.08	-9.65	5.46	0.10	-1.87	1.76
Sep	-5.79	0.36	0.93	1.84	-10	3.16	0.26	-1.63	1.37
Oct	-1.87	0.35	-3.48	8.36	-7.61	-4.86	1.61	-0.63	-0.98
Nov	-5.79	0.72	0.43	0	10.92	-0.77	0	1.07	-1.06
Dec	-9.2	1.04	-0.27	0	4.21	-0.48	0	0.22	-0.23

Note: Pre= Precipitation; Tem= Temperature; CG= contribution of glacier runoff to total runoff; CS= contribution of snowmelt runoff to total runoff; CR= contribution of rainfall runoff to total runoff.

Table S3. Projected changes (%) in mean annual and seasonal total runoff and its three components (rainfall, snowmelt and glacier) in 2021–2050 and 2071–2100, respectively, relative to 1971–2000 under the two SSPs in the YZ basin and its two sub-basins. The uncertainties are indicated with one standard deviation.

Basin	Period	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NX	2021-2050 (SSP2-4.5)	Total	-15±3	-15±3	-10±4	-7±6	-9±7	-5±7	3±7	-3±3	-11±4	-11±5	-12±3	-14±3	-6±4
		Rainfall	-15±3	-16±3	-16±3	-14±3	-1±4	29±14	1±12	-7±9	-10±4	-12±5	-9±5	-13±4	-9±5
		Snowmelt	6±7	-6±6	-14±7	-30±5	-34±5	-14±5	33±12	19±5	-17±3	-28±3	-20±5	-11±6	-5±4
		Glacier	0±0	0±0	0±0	0±0	54±18	5±7	-4±4	-5±4	2±8	39±12	0±0	0±0	5±5
	2071-2150 (SSP2-4.5)	Total	-6±4	-6±4	0±5	8±7	5±11	1±6	14±7	9±7	2±7	5±6	-2±5	-4±4	6±6
		Rainfall	-6±4	-8±3	-8±3	-7±4	13±7	87±22	25±14	18±9	13±8	12±9	12±7	-3±4	11±7
		Snowmelt	38±17	27±11	25±11	-10±7	-30±8	-19±6	20±11	8±7	-20±3	-26±4	-9±10	13±14	-8±5
		Glacier	0±0	0±0	0±0	0±0	47±29	6±8	-1±7	1±8	9±13	57±25	0±0	0±0	9±8
	2021-2050 (SSP5-8.5)	Total	-15±3	-14±3	-10±3	-6±5	-7±7	-5±6	3±7	-2±5	-10±5	-10±5	-11±4	-13±3	-5±5
		Rainfall	-35±2	-41±2	-30±2	-36±3	24±11	320±49	157±26	8±8	-27±5	-48±3	-40±3	-29±3	-9±6
		Snowmelt	9±11	-3±8	-8±6	-28±6	-31±6	-14±6	30±10	17±4	-18±2	-30±4	-20±7	-10±8	-6±4
		Glacier	0±0	0±0	0±0	0±0	55±13	7±6	-1±4	-1±6	7±9	52±12	0±0	0±0	9±6
	2071-2150 (SSP5-8.5)	Total	11±10	12±9	25±11	50±17	50±18	34±13	54±28	47±24	35±17	42±19	27±16	16±12	40±18
		Rainfall	-18±7	-26±6	-12±8	-7±10	165±40	689±122	377±108	89±36	24±19	-14±12	-20±9	-9±9	52±24
		Snowmelt	131±32	91±21	77±21	14±15	-18±11	-22±8	19±13	14±13	-23±7	-27±8	24±16	67±21	-4±7
		Glacier	0±0	0±0	0±0	0±0	187±72	72±23	45±21	48±24	78±31	0±0	0±0	0±0	78±27
NX-BXK	2021-2050 (SSP2-4.5)	Total	-17±3	-18±3	-20±5	-10±9	-15±7	-18±6	-10±6	-11±4	-16±4	-15±7	-15±4	-17±3	-14±4
		Rainfall	-16±3	-15±4	-16±5	-5±12	-16±11	-21±9	-19±7	-19±5	-23±5	-20±7	-17±4	-17±2	-19±5
		Snowmelt	-38±6	-43±4	-36±5	-27±6	-26±5	-20±4	14±8	33±7	48±7	-9±9	-27±8	-31±7	-6±4
		Glacier	0±0	0±0	0±0	0±0	77±14	-1±6	-10±5	-16±3	-14±4	4±8	0±0	0±0	-7±4
	2071-2150	Total	-10±4	-9±6	-9±6	9±13	6±12	-5±8	3±11	-2±8	-4±9	1±12	-8±5	-10±4	-1±7

	(SSP2-4.5)	Rainfall	-9±3	-8±5	-3±6	13±16	15±18	1±12	1±12	-5±10	-7±9	-5±12	-10±5	-10±4	-2±8
		Snowmelt	-24±11	-26±9	-27±7	-8±10	-15±8	-16±9	15±8	34±7	62±24	23±19	-24±9	-19±7	1±5
		Glacier	0±0	0±0	0±0	0±0	95±32	5±10	-5±10	-13±8	-12±7	21±14	0±0	0±0	-1±8
	2021-2050 (SSP5-8.5)	Total	-17±3	-18±4	-20±3	-12±5	-16±5	-18±5	-10±4	-10±3	-13±4	-13±9	-13±5	-16±3	-13±3
		Rainfall	-16±3	-15±4	-15±4	-6±6	-17±5	-23±9	-20±6	-19±5	-21±5	-18±9	-17±4	-17±3	-19±5
		Snowmelt	-38±4	-42±7	-37±4	-31±6	-26±4	-19±4	15±5	33±6	52±6	-6±12	-25±9	-32±8	-5±2
		Glacier	0±0	0±0	0±0	0±0	81±15	2±7	-7±4	-13±4	-11±5	10±7	0±0	0±0	-4±4
	2071-2150 (SSP5-8.5)	Total	2±6	6±7	21±12	51±23	45±19	21±16	24±19	24±16	22±17	34±20	11±11	3±7	25±14
		Rainfall	0±6	4±6	23±13	55±31	62±27	39±25	21±25	10±18	1±15	10±15	-1±7	-2±6	18±14
		Snowmelt	4±17	-6±8	-6±13	16±15	-2±14	-17±10	12±7	73±16	171±45	95±47	4±17	10±15	17±7
		Glacier	0±0	0±0	0±0	0±0	291±85	74±28	42±24	27±19	33±20	0±0	0±0	0±0	57±25
YZ	2021-2050 (SSP2-4.5)	Total	-16±3	-16±3	-17±3	-9±8	-14±7	-13±6	-5±6	-6±3	-13±4	-13±6	-13±4	-15±3	-10±4
		Rainfall	-16±3	-15±3	-15±3	-5±9	-9±11	-12±9	-15±7	-13±4	-18±4	-15±6	-15±3	-16±3	-14±5
		Snowmelt	-20±6	-33±4	-30±5	-28±5	-30±5	-20±4	21±8	28±6	-2±3	-26±4	-24±4	-22±5	-5±3
		Glacier	0±0	0±0	0±0	0±0	70±16	4±6	-7±4	-12±3	-9±5	13±9	0±0	0±0	-2±4
	2071-2150 (SSP2-4.5)	Total	-7±4	-8±4	-6±5	8±10	6±12	-3±7	7±8	5±7	0±8	2±9	-4±5	-7±4	2±6
		Rainfall	-8±3	-8±4	-5±4	11±12	26±18	11±12	7±9	6±9	2±9	3±9	-6±4	-8±3	4±7
		Snowmelt	3±12	-12±9	-15±7	-7±9	-21±7	-19±7	15±8	21±6	-2±6	-20±4	-15±9	-5±10	-4±4
		Glacier	0±0	0±0	0±0	0±0	74±30	8±9	-3±8	-8±8	-5±9	31±17	0±0	0±0	3±8
	2021-2050 (SSP5-8.5)	Total	-16±2	-16±2	-16±2	-10±4	-14±5	-13±5	-5±5	-5±3	-11±5	-11±6	-12±4	-14±3	-9±4
		Rainfall	-16±3	-16±3	-15±3	-6±5	-10±6	-14±9	-15±6	-12±5	-16±5	-14±7	-14±4	-16±3	-14±5
		Snowmelt	-19±5	-32±6	-29±3	-30±5	-28±4	-20±4	20±7	27±5	-2±3	-27±4	-24±6	-22±6	-6±3
		Glacier	0±0	0±0	0±0	0±0	72±14	6±6	-4±4	-9±4	-5±6	21±9	0±0	0±0	2±5
	2071-2150 (SSP5-8.5)	Total	7±8	9±8	21±9	50±19	47±18	27±14	35±21	38±21	30±17	37±18	21±14	11±9	32±15
		Rainfall	3±7	5±7	16±9	49±23	79±28	58±25	42±29	38±24	28±18	30±17	11±11	5±8	33±18
		Snowmelt	56±20	21±11	14±14	18±14	-8±12	-20±9	12±5	40±14	14±11	-13±11	12±14	36±17	5±6
		Glacier	0±0	0±0	0±0	0±0	250±81	80±26	44±22	34±21	46±23	0±0	0±0	0±0	65±26

Table S4. Projected changes (%) in mean annual and seasonal precipitation in 2021–2050 and 2071–2100, respectively, relative to 1971–2000 under the two SSPs in the YZ basin and its two sub-basins. The uncertainties are indicated with one standard deviation.

Basin	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NX	2021-2050 (SSP2-4.5)	-1.5±5.7	0.1±7.3	-4.1±4.7	6.9±7.8	18.4±10	10.5±8.5	11.4±3.8	1.2±4.0	3.7±5.4	6.6±5.43	-10.8±9	-11.8±13	6.50±3.3
	2071-2100 (SSP2-4.5)	-0.1±9	1.8±7.6	-2.9±5.9	14.2±14	25.4±10	15.4±8.5	18.1±4.9	9.0±4.80	11.9±5.2	14.8±8.9	-12.6±9	-12.3±13	12.8±3.8
	2021-2050 (SSP5-8.5)	-0.5±7.6	1.2±4.7	1.02±7.1	10.9±9.4	20.2±9	8.7±10.1	10.1±4.8	2.7±4.6	2.8±5.2	3.2±8.3	-13.6±8	-14.5±9	6.42±3.7
	2071-2100 (SSP5-8.5)	3.69±10	6.41±7.7	5.95±8.8	29.9±18	49.2±13	34.9±14	36.5±18	24±11.3	22.3±7.9	40.8±14	3.5±12.4	-9.5±10	29.4±9.6
NX-BXK	2021-2050 (SSP2-4.5)	-1.1±11	-3.4±5.1	-3.6±8.4	2.5±11.8	9.7±9.9	-0.2±5.8	1.94±7.8	-3.4±4.5	-9.5±6.1	-7.2±9.7	-15.4±12	-11±9.9	-1.9±3.8
	2071-2100 (SSP2-4.5)	2.8±11.6	-1.1±8.4	1.04±9.2	12.2±14	22.9±14	4.74±6.6	11.5±11	-0.1±8.6	-2.7±9.9	-1.6±13	-14.2±11	-10±11	4.55±5.1
	2021-2050 (SSP5-8.5)	-3.1±7.8	-4.4±7.3	-1.6±5.2	-0.1±6.9	9.91±5.9	-2.7±6.9	0.68±6.7	-3.3±6.1	-7.5±5.8	-7.9±13	-15.5±9	-16±9.3	-2.6±3.3
	2071-2100	9±13	4.13±6.3	15.3±16	32.8±21	41.4±18	17.5±14	22.2±20	8.8±16.8	-1.6±10	11.9±15	-1.8±13	-7.8±18	15.6±8.7

	(SSP5-8.5)													
YZ	2021-2050 (SSP2-4.5)	-1.3±8.7	-2.2±5.7	-3.8±6.5	4.19±9.9	14±9.8	6±7	8.2±4.9	-0.1±3.7	-1.8±4.7	-1.1±7	-13±10	-11.3±10	2.76±3.3
	2071-2100 (SSP2-4.5)	1.7±10.3	-0.1±7.6	-0.2±7.4	13±14	24.1±11	11±6.23	15.9±6	6.3±5.68	5.7±6.37	5.5±10.8	-13.5±10	-10±11	9.2±4.28
	2021-2050 (SSP5-8.5)	-2.1±7.2	-2.5±5.5	-0.8±5.6	4±7	15±6.3	4±8.2	6.9±4.84	1±4.5	-1.5±4.8	-3±10.2	-14±7.7	-15±8.4	2.4±3.2
	2071-2100 (SSP5-8.5)	7±11.9	4.9±5.9	12.4±13	31.7±19	45.3±14	27.7±13	31.6±18	20.2±11	12.2±8.1	24.6±14	0.3±12.9	-8±14.8	23.3±8.7

Table S5. Projected changes (℃) in mean annual and seasonal temperature in 2021–2050 and 2071–2100, respectively, relative to 1971–2000 under the two SSPs in the YZ basin and its two sub-basins. The uncertainties are indicated with one standard deviation.

Basin	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NX	2021-2050 (SSP2-4.5)	1.43± 0.35	1.04± 0.535	1.139± 0.527	1.428± 0.607	1.231± 0.524	1.023± 0.348	0.835± 0.209	0.939± 0.26	1.027± 0.383	0.838± 0.184	1.372± 0.507	1.657± 0.597	1.163± 0.279
	2071-2100 (SSP2-4.5)	3.192± 0.935	2.952± 0.651	2.93± 0.51	3.226± 0.678	2.95± 0.795	2.541± 0.42	2.412± 0.468	2.459± 0.46	2.58± 0.606	2.55± 0.508	3.508± 1.097	3.787± 0.9	2.924± 0.472
	2021-2050 (SSP5-8.5)	1.599± 0.29	1.34± 0.543	1.341± 0.335	1.42± 0.378	1.178± 0.422	1.111± 0.336	1.061± 0.258	1.147± 0.288	1.207± 0.395	1.256± 0.196	1.821± 0.728	1.953± 0.443	1.369± 0.222
	2071-2100 (SSP5-8.5)	6.227± 0.778	5.826± 0.634	5.72± 0.805	5.982± 1.252	5.435± 1.095	4.735± 0.838	4.535± 1.064	4.721± 1.158	5.05± 1.05	5.558± 1.224	6.679± 1.684	6.916± 1.489	5.615± 0.853
NX-BXK	2021-2050 (SSP2-4.5)	0.88± 0.454	0.56± 0.475	0.274± 0.396	0.537± 0.349	0.427± 0.207	0.32± 0.326	0.465± 0.326	0.543± 0.311	0.671± 0.323	0.327± 0.303	0.708± 0.334	1.204± 0.534	0.576± 0.246
	2071-2100 (SSP2-4.5)	2.55± 0.974	2.291± 0.655	1.88± 0.588	2.245± 0.557	2.083± 0.458	1.895± 0.66	2.036± 0.763	2.027± 0.58	2.162± 0.553	1.923± 0.601	2.64± 0.749	3.152± 0.979	2.24± 0.51
	2021-2050 (SSP5-8.5)	1.108± 0.168	0.791± 0.45	0.446± 0.268	0.505± 0.295	0.515± 0.294	0.508± 0.404	0.721± 0.293	0.783± 0.317	0.839± 0.32	0.712± 0.22	1.181± 0.4	1.54± 0.296	0.804± 0.164

	2071-2100 (SSP5-8.5)	5.406± 0.841	4.852± 0.654	4.365± 0.785	4.656± 1.02	4.269± 0.82	3.823± 1.033	4.008± 1.191	4.246± 1.349	4.551± 1.048	4.719± 1.299	5.692± 1.329	6.303± 1.409	4.741± 0.902
YZ	2021-2050 (SSP2-4.5)	1.319± 0.358	0.942± 0.511	0.963± 0.488	1.246± 0.541	1.069± 0.441	0.88± 0.332	0.761± 0.214	0.858± 0.258	0.954± 0.37	0.735± 0.191	1.236± 0.437	1.564± 0.576	1.044± 0.259
	2071-2100 (SSP2-4.5)	3.064± 0.933	2.818± 0.641	2.716± 0.519	3.026± 0.636	2.774± 0.688	2.409± 0.433	2.335± 0.506	2.37± 0.477	2.495± 0.594	2.424± 0.512	3.331± 0.991	3.658± 0.896	2.785± 0.465
	2021-2050 (SSP5-8.5)	1.501± 0.234	1.229± 0.512	1.159± 0.311	1.233± 0.348	1.043± 0.367	0.989± 0.344	0.992± 0.249	1.072± 0.278	1.132± 0.378	1.146± 0.192	1.69± 0.642	1.869± 0.396	1.254± 0.198
	2071-2100 (SSP5-8.5)	6.061± 0.768	5.628± 0.619	5.444± 0.793	5.712± 1.188	5.198± 0.955	4.55± 0.864	4.428± 1.088	4.624± 1.195	4.948± 1.048	5.388± 1.228	6.477± 1.537	6.79± 1.427	5.437± 0.846