International Network for Alpine Research Catchment Hydrology (INARCH)
2026 Annual INARCH Workshop
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September 8–10, 2026

Hydrologic modeling at the source of Yellow River Basin on Tibetan Plateau

DI LIU

COLLEGE OF HYDROLOGY AND WATER RESOURCES

HOHAI UNIVERSITY

OUTLINE

1 Background

2 In-situ Experimental Sites

3 Hydrologic Modeling

4 Following Work

01 Background

Floods, Snow Avalanche and Glacial Debris Flow — Time and Place of Five Disasters

Official sources: Xinhua News Agency, CCTV, People's Daily and provincial governments (Guangxi · Heilongjiang · Liaoning · Xizang). Impact figures as-of-dated.

17–20 Jan 2026 Paimo Highway Snow Avalanche — Nyingchi, Xizang

Type: snow avalanche · Duoxiongla Tunnel section, Pai–Mêdog (Paimo) road, Nyingchi

28 people killed (by 20 Jan 17:30); 1,348 rescuers and 236 machines mobilised; 7.5 km of avalanche debris cleared (CCTV/Xinhua).

4–8 Jul 2026 Extreme Rain and River Floods — Guangxi

Type: flood · Typhoon No.10 "Maysak"; ~77% of townships hit by torrential rain; Liulan and other reservoirs overtopped (*375,000 people affected across 63 counties / 14 cities; 6 dead, 11 missing, ~130,000 relocated — as of 7 Jul 20:00 (Guangxi govt. briefing)).*

13–14 Jul 2026 Rainstorm and Urban Flooding — Shenyang, Liaoning

Type: flood · Tropical Storm "Bavi"; red alert and top-level flood response in Shenyang

Liaoning: over 260,000 people evacuated by 14 Jul; Shenyang max rainfall 207.2 mm, peak intensity 66 mm/h (Xinhua).

8–12 Aug 2026 River Floods — Heilongjiang Province

Type: flood · Songhua & Heilong (Amur) rivers, main flood season

Songhua No.1 flood peak passed Tongjiang on 7 Aug; Amur (Heilongjiang) main-stem blue warning at Tongjiang issued 8 Aug (Xinhua / provincial govt.).

26 Aug 2026 Glacial Debris Flow — Gyirong Port, Shigatse, Xizang

Type: debris flow · transboundary: ice-rock avalanche on the Nepal side (Mt. Langtang Lirung) ran ~22 km into China (*31 dead, 531 missing (Xizang side, 18:00 4 Sep); classic cross-border "disaster cascade" under climate warming (CAS)).*

Notes: each event shows date window and location with official key figures. Media © Xinhua/CCTV. Compiled from official reporting for academic discussion (Sep 2026); casualty/impact numbers are as-of-dated and subject to official revision — verify before citing.

Gyirong Port Mudslide (26 August 2026): A Transboundary Glacial Disaster Chain from Nepal to China

Official sources: Xinhua News Agency · People's Daily · Government of Xizang (TAR) briefings · CAS Institute of Mountain Hazards & Environment. Casualty data as of 18:00, 4 Sep 2026 (subject to revision).

1 · CAUSE & TRANSBOUNDARY DISASTER CHAIN

- On 26 Aug 2026 an ice–rock avalanche released from a high-mountain glacier on the north slope of Mt. Langtang Lirung, Nepal (~5,200 m ASL) and plunged to ~4,000 m.
- The fast-moving mass became a debris/mud flow that ran ~22 km down the river valley and hit Gyirong Port (~1,800 m), China's principal land port to Nepal.
- Identified by CAS Inst. of Mountain Hazards & Environment from satellite + field data (Kang Shichang); classed by CAS academician Yao Tandong as a classic cascading disaster — energy amplified down-valley, then crossing the international border.
- **Root cause:** long-term glacier instability under climate warming (Su Pengcheng, CAS) — a climate-driven transboundary chain.

2 · IMPACT

- ~0.7 km² flattened; 27 buildings & facilities destroyed; the G216 road, power and telecom links severed at the port.
- Debris/silt in the core zone exceeded 1.5 m deep, severely hampering search and rescue.

3 · OFFICIAL CASUALTY COUNT — XIZANG/CHINA SIDE (AS REPORTED)

- 5 dead · 558 missing (28 Aug, 15:00) → 16 · 546 (29 Aug, 18:00) → 21 · 541 (2 Sep, 12:00) → 31 dead · 531 missing (4 Sep, 18:00).
- 847 items of personal effects recovered; 876 enquiries from relatives received and answered.

4 · RESPONSE, RECOVERY & OUTLOOK

- 2,300+ rescuers (later 2,500+), 400+ vehicles, 8,000+ equipment sets; 24 helicopter and 800+ drone flights; 5.43 t of supplies airdropped.
- Multi-pronged land–water–air search; 12 telecom base stations restored; G216 reopened toward the port.
- The upstream barrier lake was drained and river flow normalized in early Sep — the residual hazard is largely removed; glacial monitoring & cross-border early warning remain the key open research and policy needs.

Note: figures are official, as-of-dated, and remain subject to revision as search, recovery and identification continue.

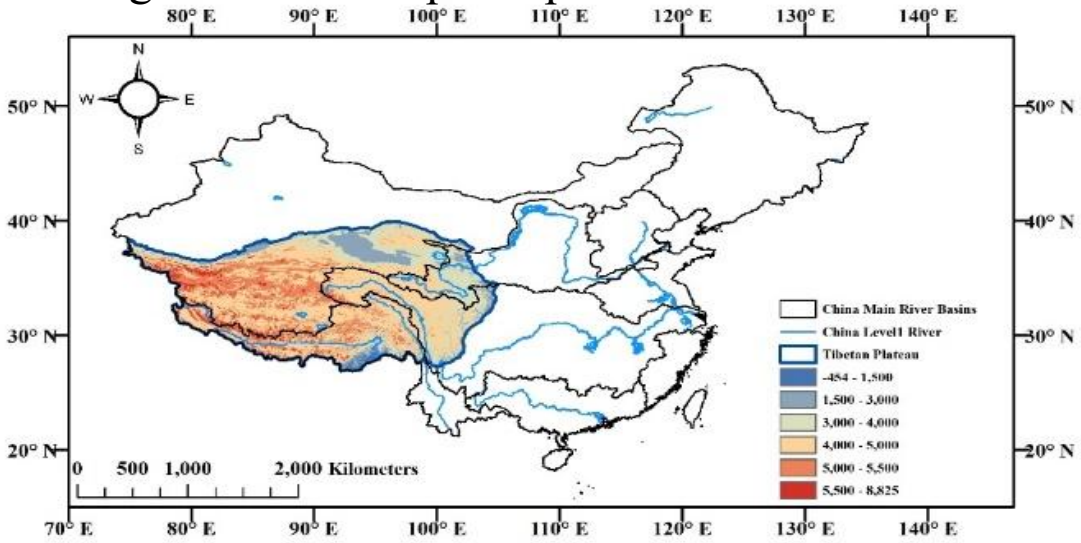
Video — aerial footage of the mudslide-hit area around Gyirong Port, filmed 28 Aug 2026.

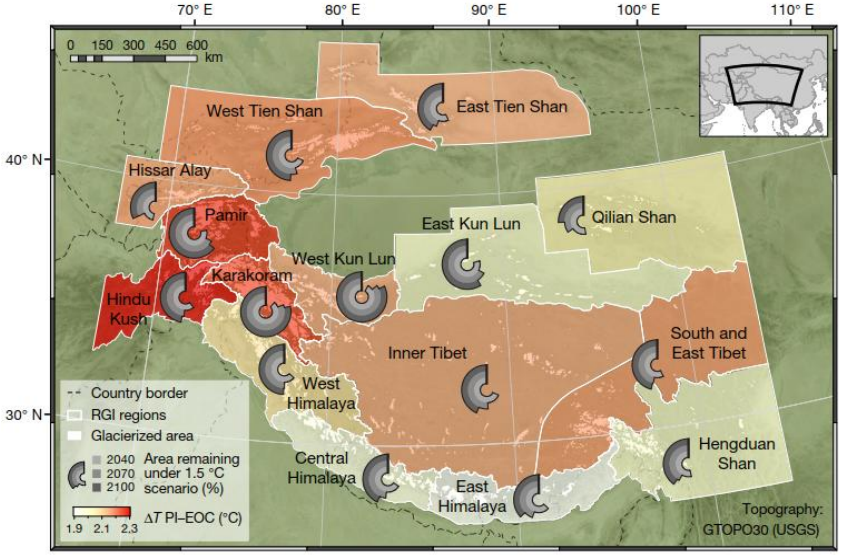
Still images (a–d) — all Xinhua official photos, disaster & rescue scenes, 27 Aug – 2 Sep 2026.

KEY RESEARCH MESSAGE Climate-driven glacial instability can cascade across an international border within minutes — joint monitoring, forecasting and early warning are the priority.

Climate change on Tibetan Plateau

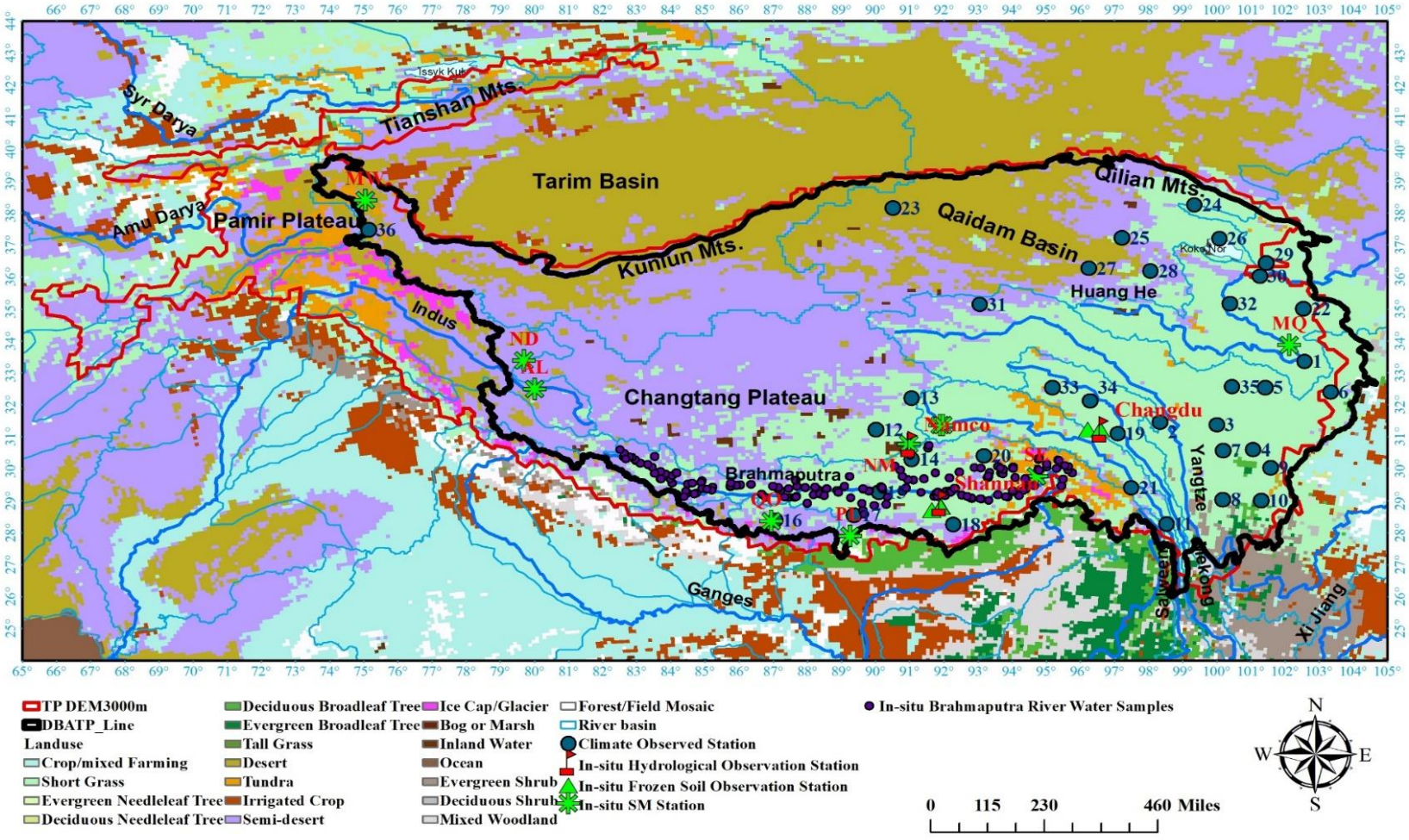
- TP, **Third pole and Asian water tower**, average elevation above 4000 m, source of more than ten large rivers of Asia, feeding over 1/3 world's population. (Yang et al. 2014)
- TP exerts profound impact on Asian monsoon and global climate due to its huge terrain and strong thermal effects on land-atmosphere-ocean interactions (Liu et al., 2020)
- More sensitive to global climate change. 1.5 Celsius global temperature increase would exert more warming at TP (Kraaijenbrink et al., 2017)(Yao et al., 2019)
- **Climate change speed up water cycle over TP (Li et al., 2015):** solid-state water (snow, ice, glacier, and permafrost) decreased, active layer of permafrost and melting water increased, ET increased, prec and runoff changes with clear spatial pattern





Research Interest

- Mechanism of Land-Atmosphere Interactions over TP, especially the land-atmosphere coupling on hydrologic cycle and extreme events diagnosis
- Mechanisms of hydrologic processes under changing environment through in-situ experiments
- Numerical hydrologic modeling and local runoff forecast



02 In-situ Experimental Sites

Shannan Yala Shampoo Cryosphere Hydro-Ecological Monitoring Station

- **Location**: N28°55 ", E91°53 ". originates from Yala Xiangpo snow Mountain on north slope of Himalayas. Modern glaciers widely developed. Glacier area in summer about 10.1 km2.

- **LUCC**: Rhodiola rosea above 5000m; Grass and Round ears smartweed, bulbil smartweed meadow about 4500 ~ 5000m.

- **Ecological and environmental monitoring equipment**: monitor atmospheric, water environment, hydrology, ecology, soil, geological conditions and meteorological conditions (temperature, precipitation, radiation, relative humidity, wind direction/speed, soil temperature/moisture, permafrost changes, soil respiration, greenhouse gas emissions, runoff)

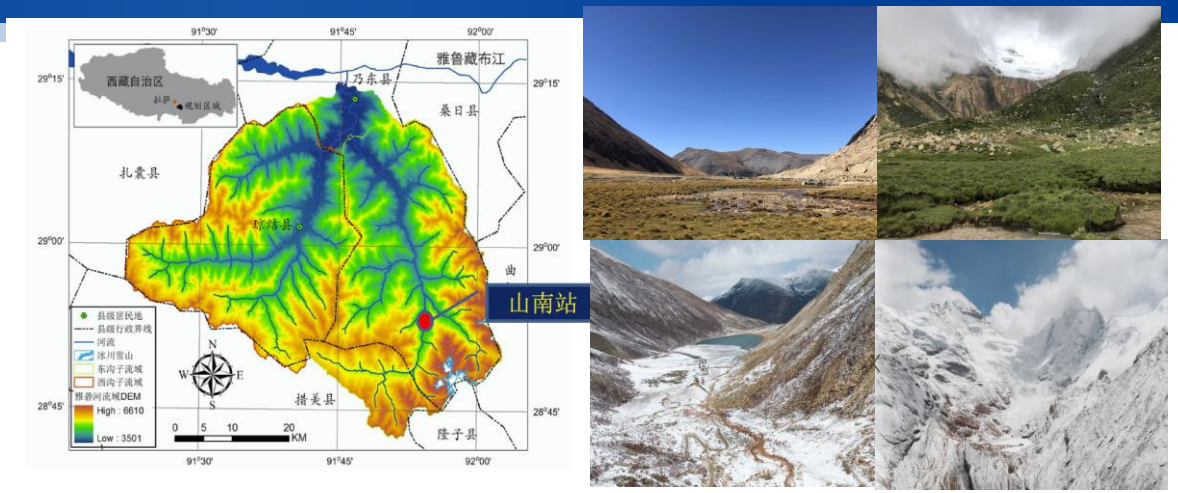


Fig. 1 Location and main sample site of Shannan Ecological monitoring Station

Fig. 2 Observation experiments carried out at Shannan Field Test Ground

Qamdo Eco-Hydrological Monitoring Station

- **Location**: 31°13 '41.91 "N, 96°35' 25.52" E, northwest of Boshula Ridge in Nianqing Tanggula Mountain and southeast of Thanyuntaweng Mountain. Upper reaches of Lancang River, middle and upper part of Jinsha River, Lancang River and Nu River.

- **LUCC**: Below 3800 m warm meadow steppe and warm steppe. 3800-4300 m: subalpine coniferous forest, i.e., spruce and macrophylla. 4300-4900m: alpine meadow mainly snow layer rhododendron, alpine kobresia, dwarf kobresia and golden dew plum. Above 4900 m: Sparse cushion vegetation.

- Has office area, living area, hydrologic experiment and analysis test center, ecological environment analysis laboratory. Can monitor atmosphere, water environment, hydrology, ecology, soil, geological conditions and meteorology (e.g.,temperature, precipitation, radiation, relative humidity, wind direction/speed, soil temperature/moisture, root growth of vegetation, leaf photosynthesis, permafrost changes, soil respiration, greenhouse gas emissions, runoff)

Fig. 1 Basics of Changdu Eco-Hydrological monitoring Station

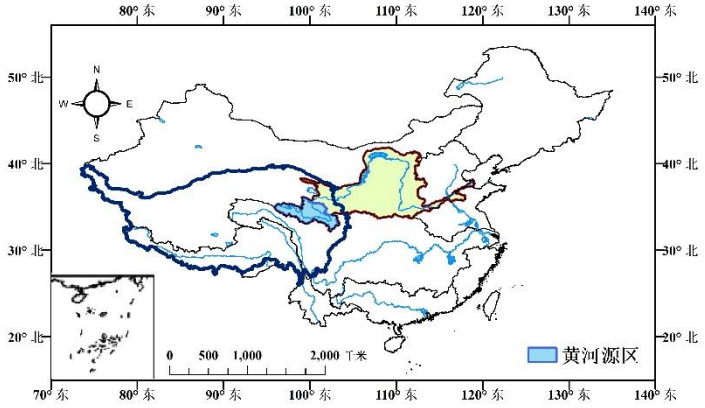
Fig. 2 Forzon Soil, Global warming air Monitoring sites

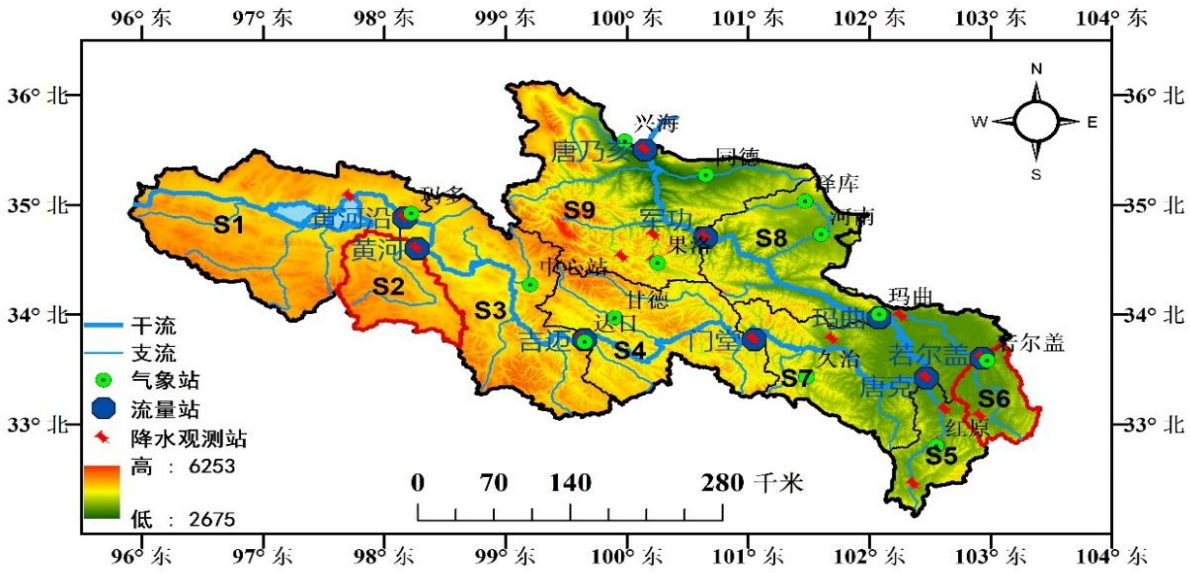
Tibetan Plateau Cold Region Laboratory

- Located at Liuwu New District, Lhasa, covering area of 1500 square meters, with 3 technicians and 36 sets of instruments and equipment.
- Has soil analysis room, sample pretreatment room, water quality testing and analysis room, atmosphere analysis room and freeze-thaw simulation room.
- Has field observation sites in Yangtze River source, Niyang River basin, upper Yalong River, Upper Lhasa River, source of Yarlung Zangbo River and Shiquan River basin, covering hydrology, water environment, atmosphere, meteorology, ecology, soil and geological disaster monitoring and assessment.

03 Hydrologic Modeling

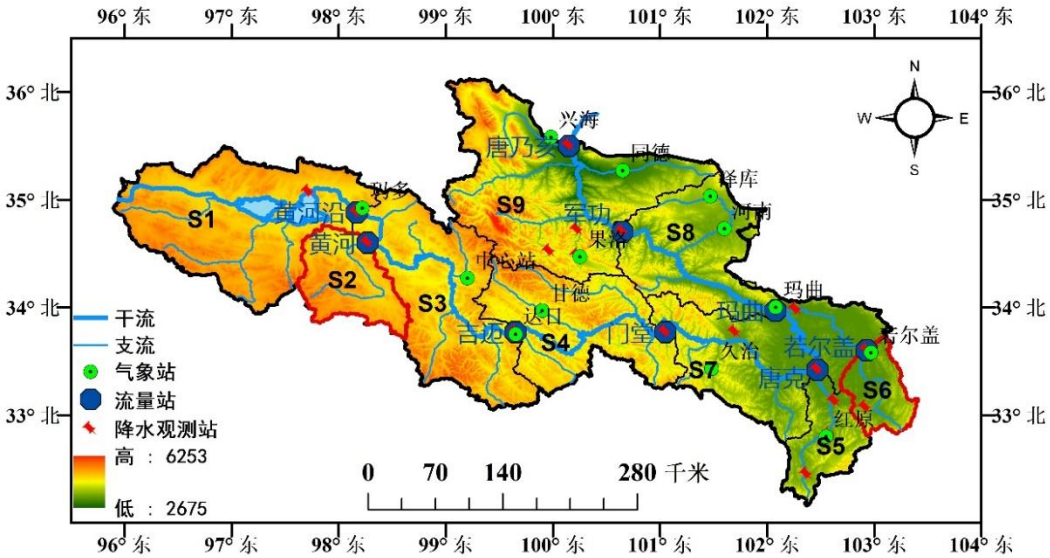
Research Area: Upper Sources of Yellow River Basin





- The source region of the Yellow River (SRYR), on the northeastern Qinghai–Tibet Plateau, is a key water-conservation area that contributes about 60% of the runoff of the Yellow River Basin from only ~15% of its area (Zhang et al., 2004) and is essential for basin-wide water security and ecological health (Wang Y.F. et al., 2021).
- The region is highly sensitive to warming (Yang et al., 2014), and permafrost is warming at a global scale (Biskaborn et al., 2019), threatening terrestrial water storage across the plateau (Li et al., 2022) and driving frozen-ground change in the source region (Jin et al., 2009; Qin et al., 2017; Wang T. et al., 2018).
- Freeze–thaw processes, snowmelt, soil-water storage, and seasonal vegetation growth jointly shape runoff generation (Gao et al., 2021); permafrost degradation and changes in near-surface freezing can alter active-layer thickness, soil-water storage, frozen-water release, and runoff recharge pathways (Bao et al., 2026).

Research Area: Upper Sources of Yellow River Basin



CRHM Model Construction Area

S2: Permafrost Area

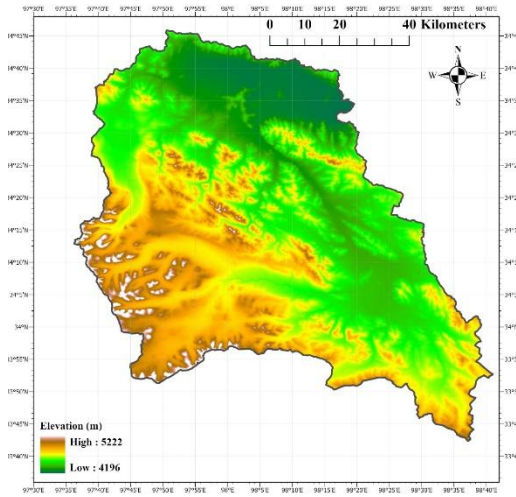
S6: Seasonally frozen area

Input Forcing Data: CMFD 2.0

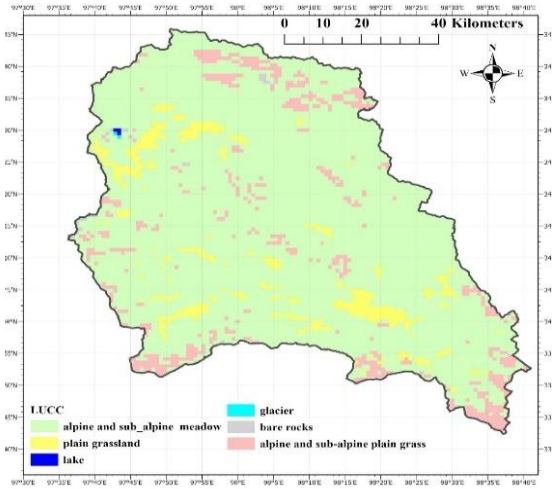
Model Validation: Observed Streamflow

Basin	Streamflow Station	Location(°)	Subbasins	HRUs	Watershed Area (km^2)
S1	Huangheyan	98.17E, 34.88N	564	2305	20930
S2	**Huanghe**	**98.27E, 34.60N**	**150**	**601**	**6446**
S3	Jimai	99.65E, 33.77N	469	1933	45019
S4	Mentang	101.05E, 33.77N	368	1434	59655
S5	Tangke	102.47E, 33.42N	138	769	5374
S6	**Ruoergai**	**102.93E, 33.60N**	**88**	**323**	**4001**
S7	Maqu	102.08E, 33.97N	435	1861	86048
S8	Jungong	100.65E, 34.70N	339	1131	98414
S9	Tangnaihai	100.15E, 35.50N	626	2894	121973

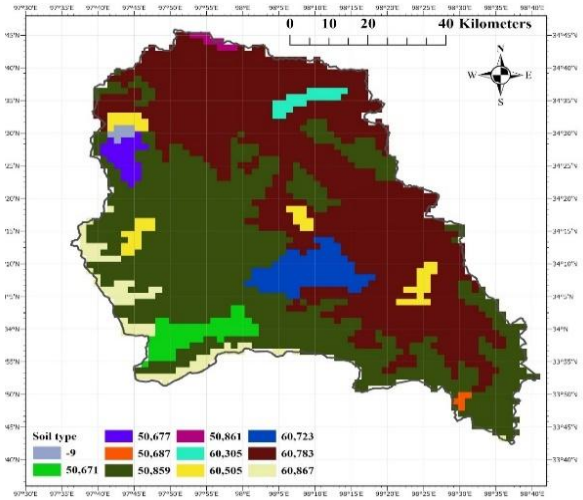
S2: The Upper Basin of Huanghe Station



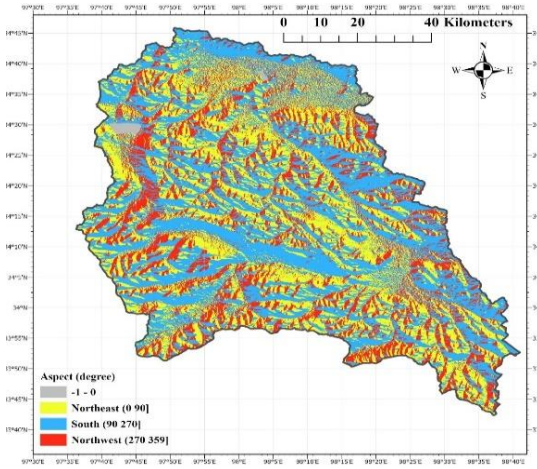
Elevation



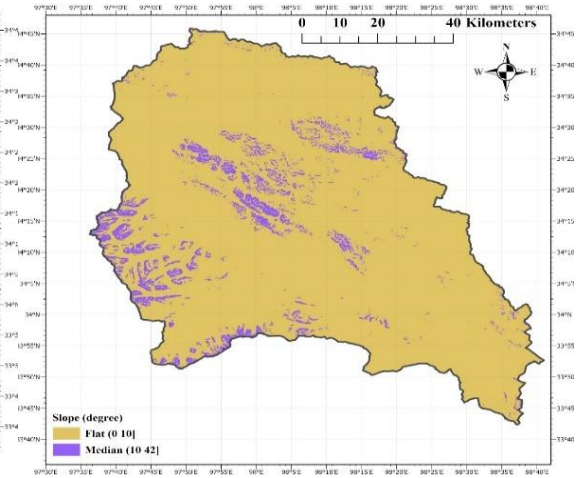
LUCC



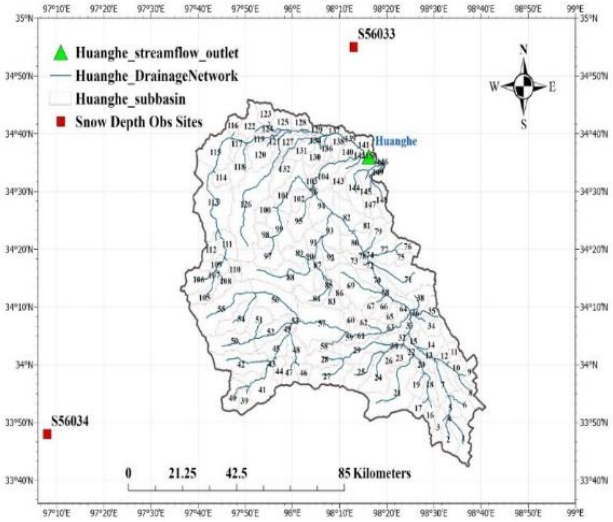
Soil Type



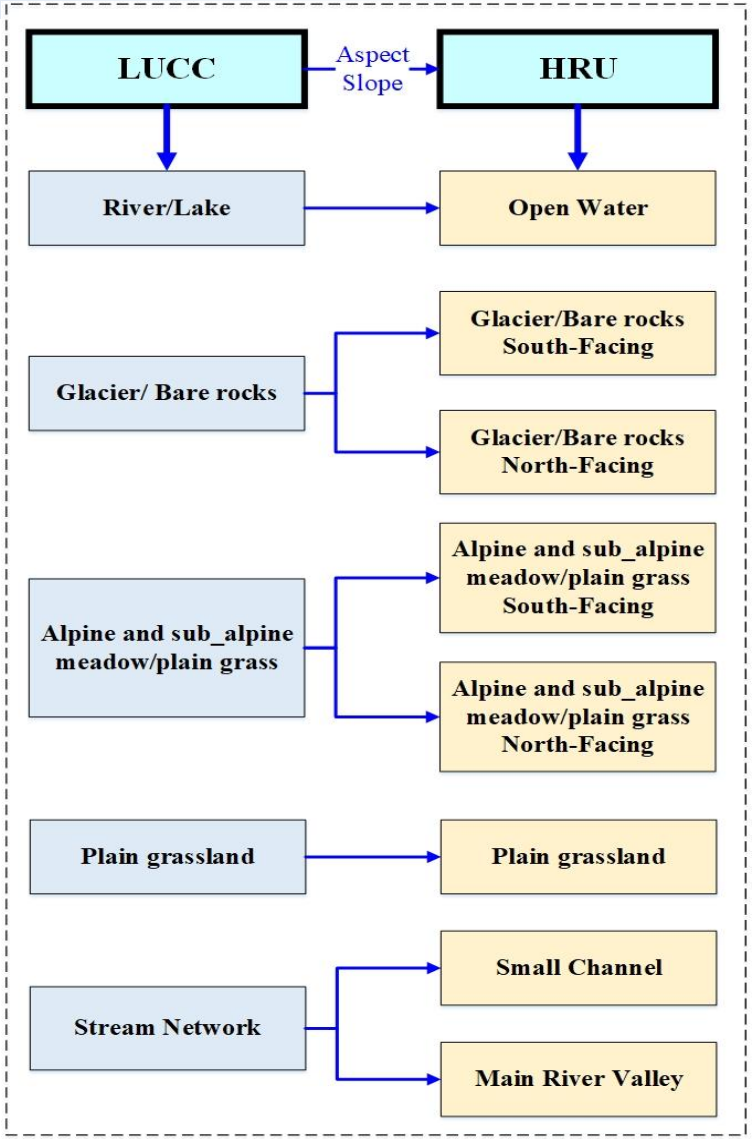
Aspect



Slope

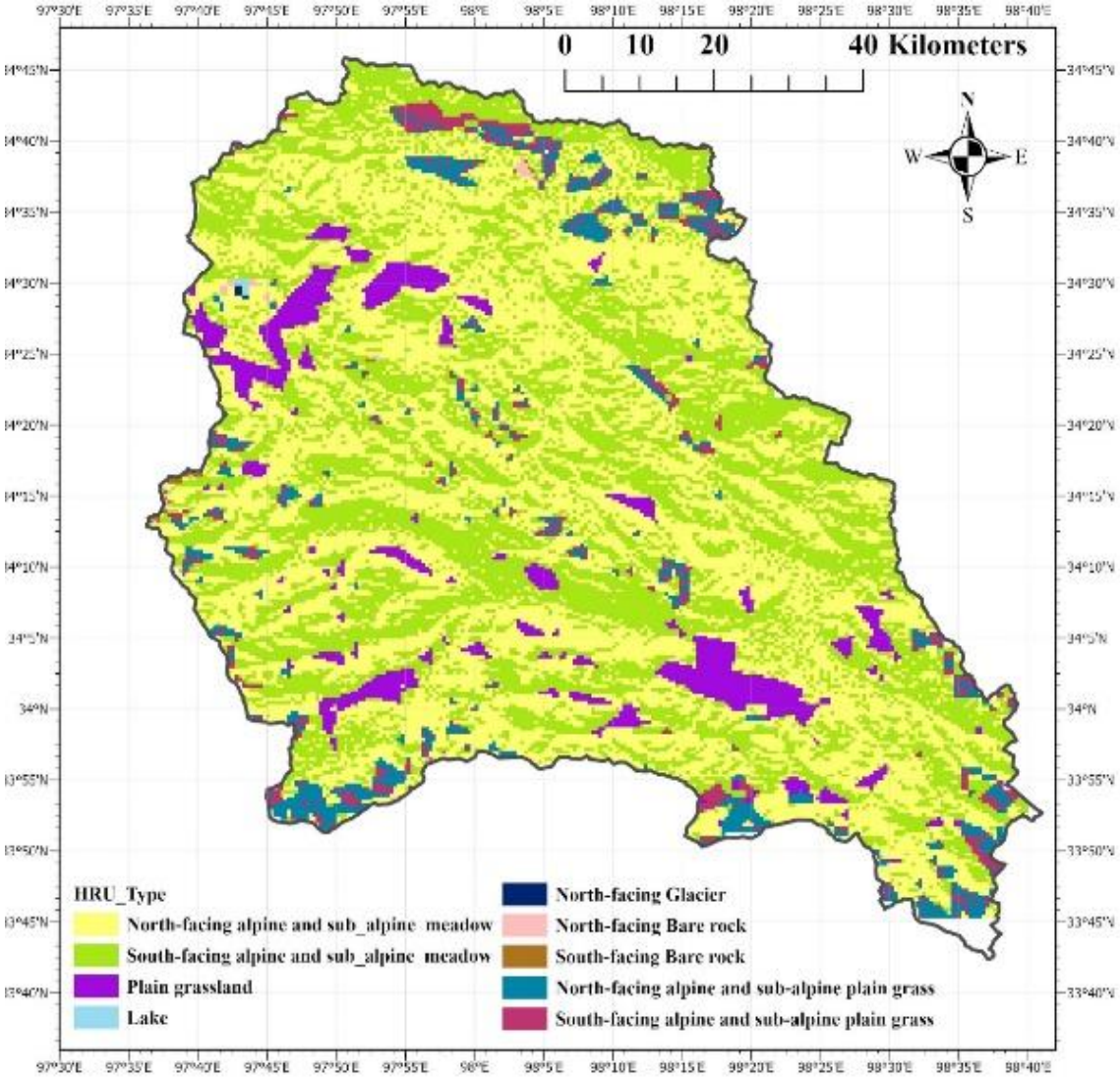


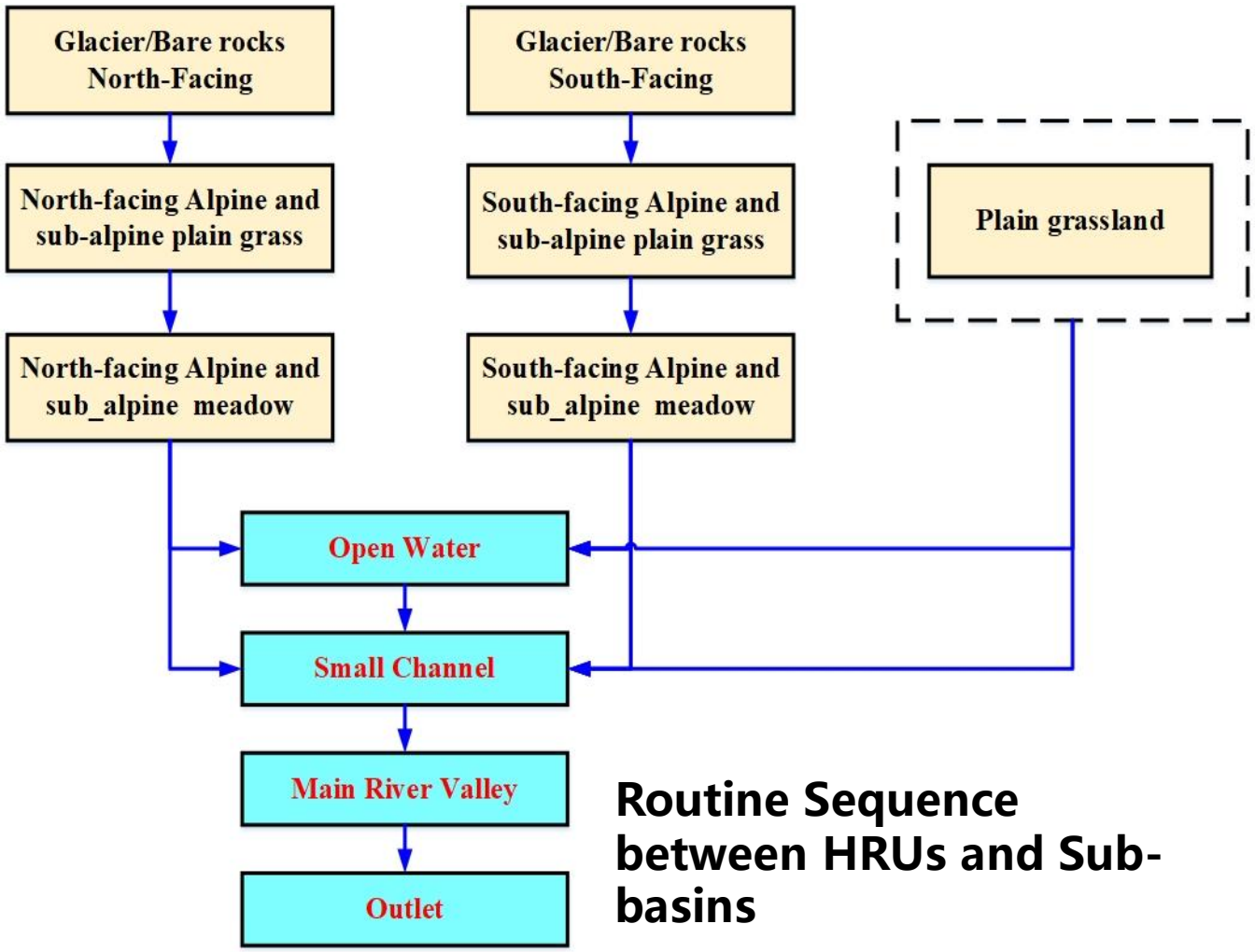
Drainage System



Fang and Pomeroy, 2023)

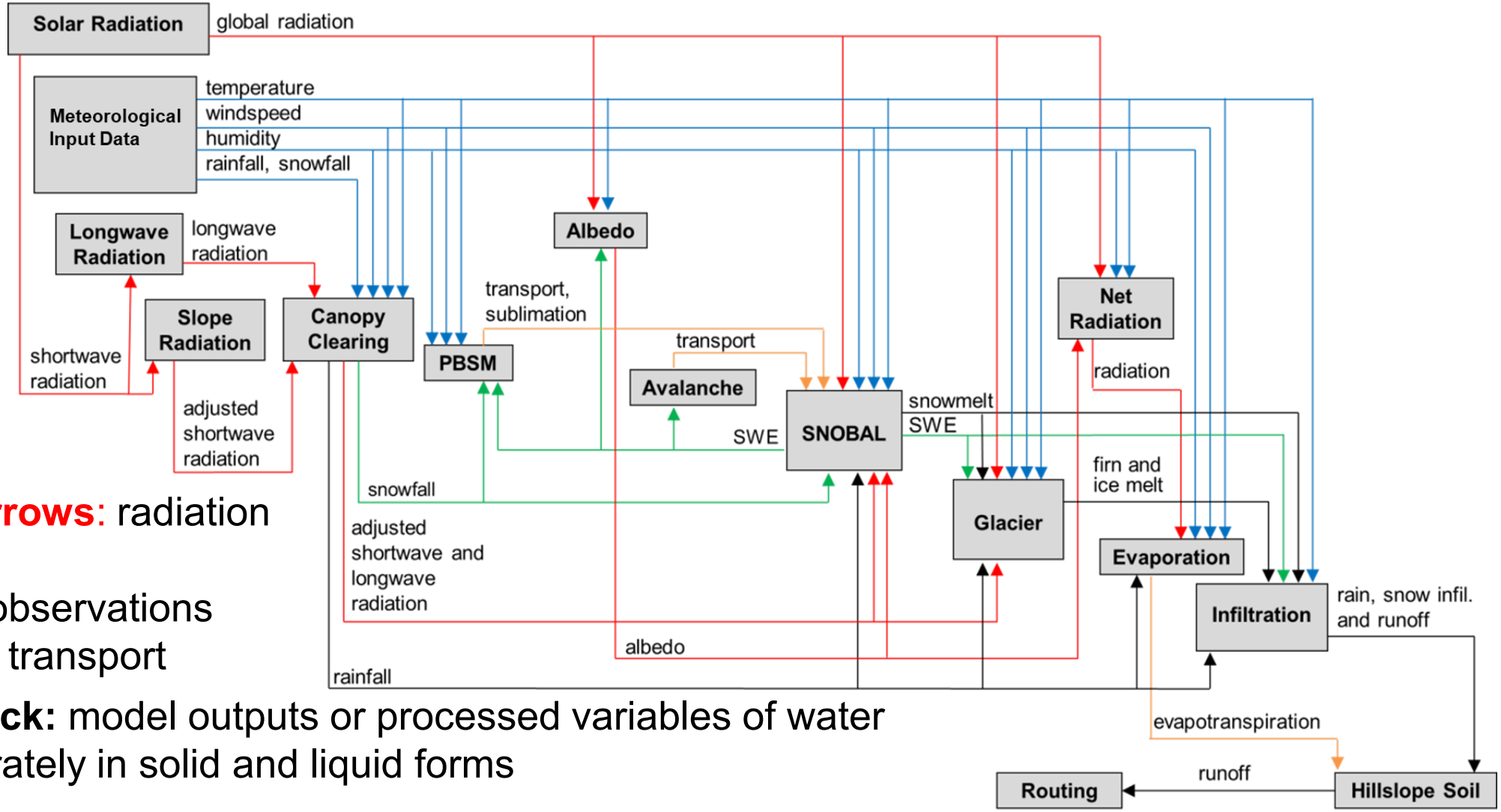
Spatial Distribution of HRU and Routine Sequence between HRUs and Sub-basins





Routine Sequence between HRUs and Sub-basins

Flowchart of CRHM Modules Used at Glacier Area



- **Red linking arrows**: radiation terms
- **Blue:** climate observations
- **Orange:** mass transport
- **Green and black:** model outputs or processed variables of water equivalents separately in solid and liquid forms

(Pradhananga and Pomeroy, 2022)

Results Analysis

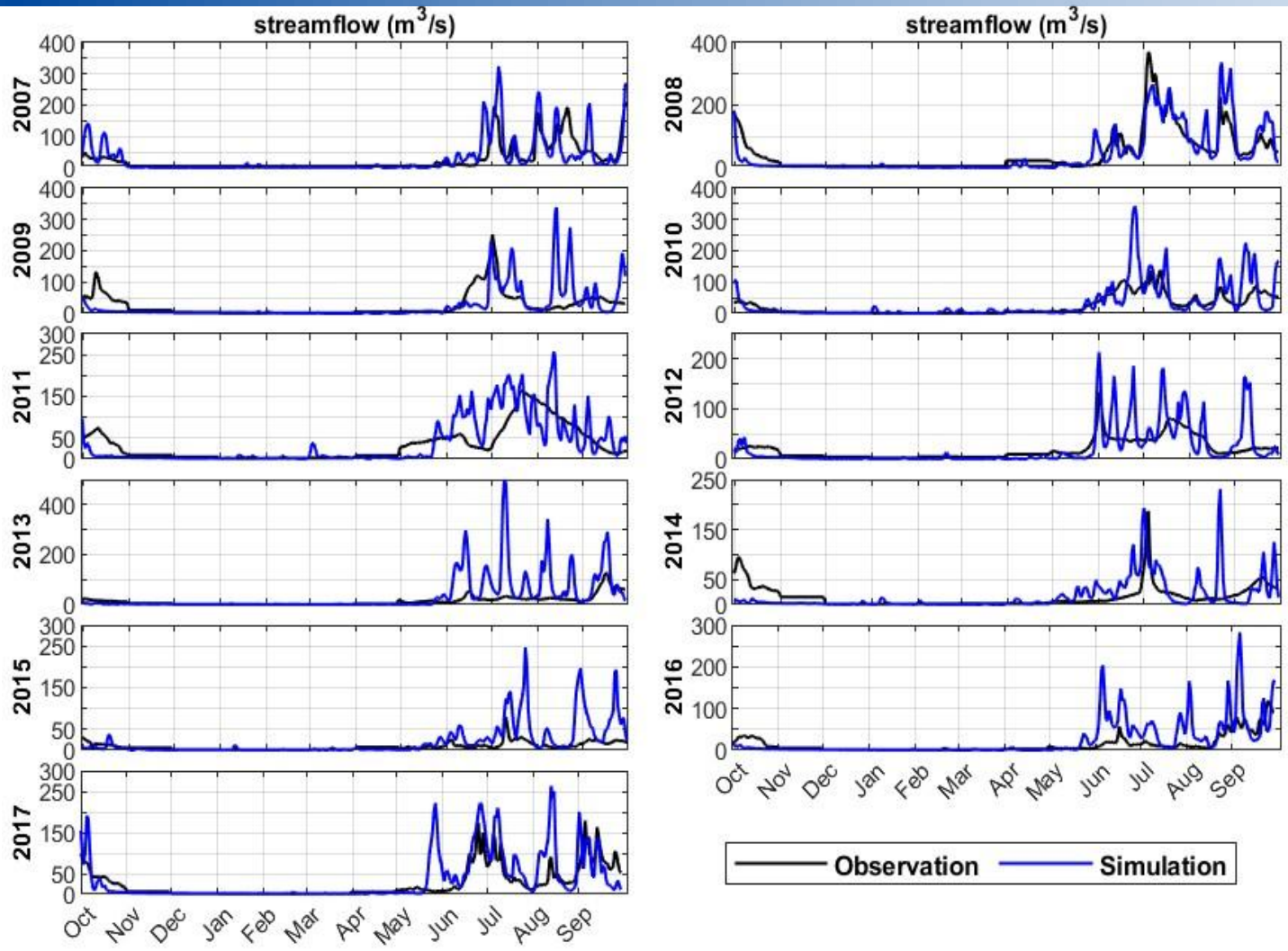


Figure 1: Daily time series of simulated streamflow versus the observed streamflow in each hydrology year during Oct-1st-2007 to Sep-30th-2017.

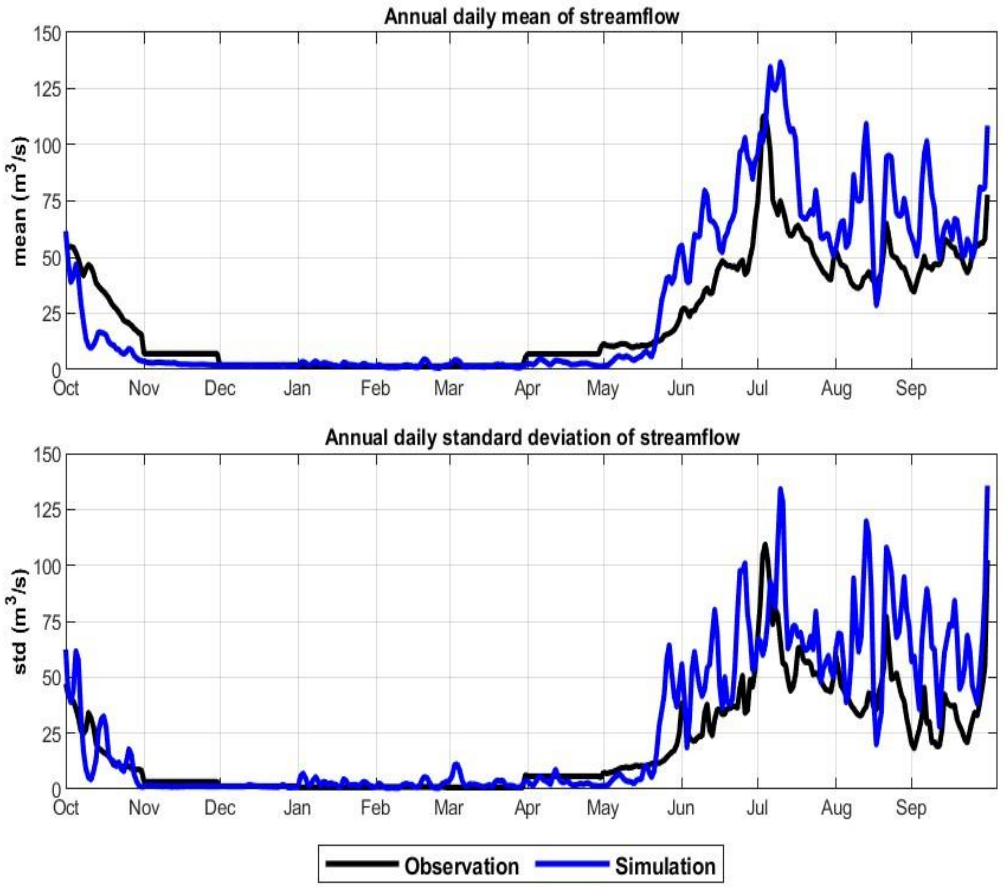
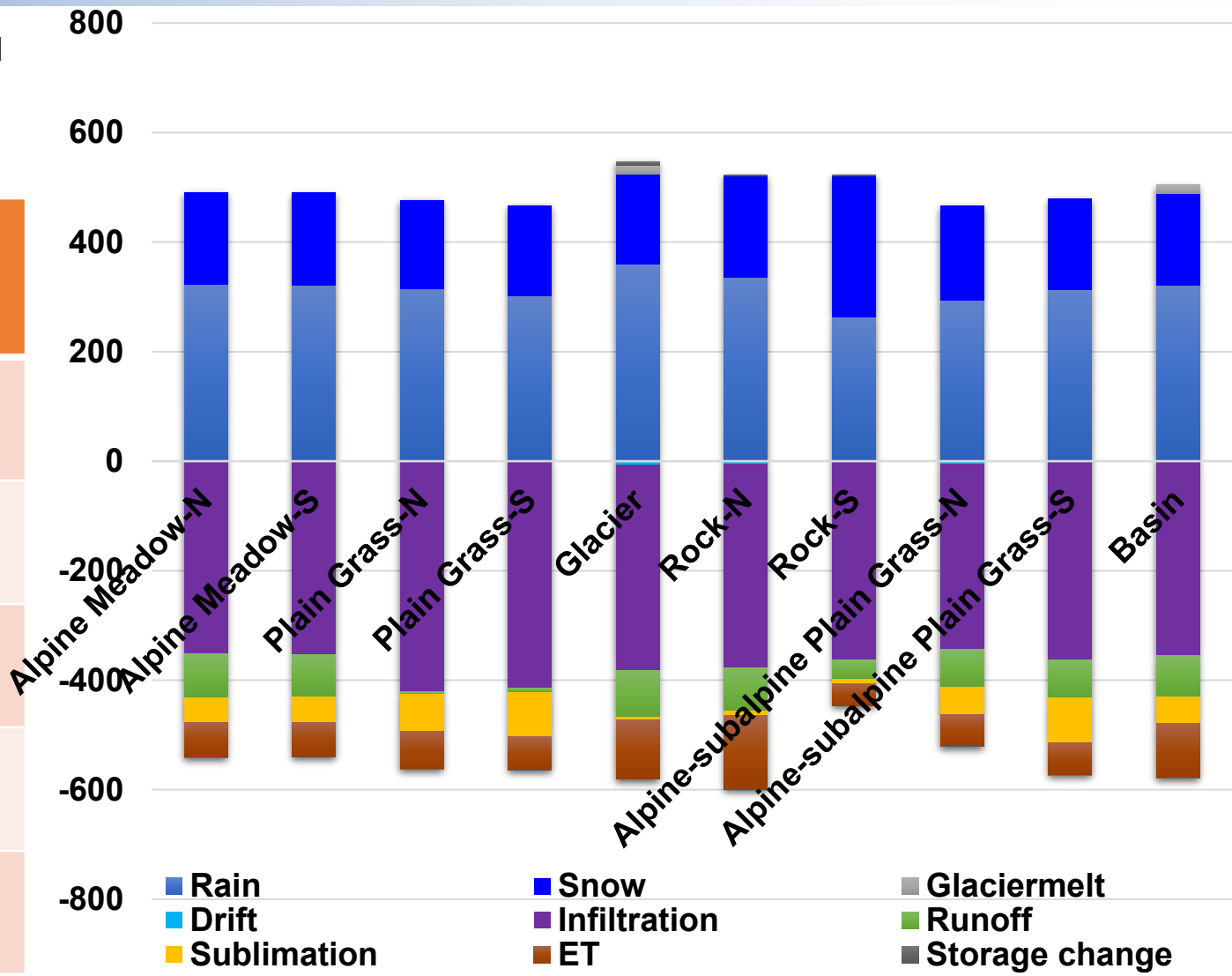


Figure 2: Daily mean and standard deviation of simulated streamflow versus the observed streamflow during years 2007-2018.

Results Analysis

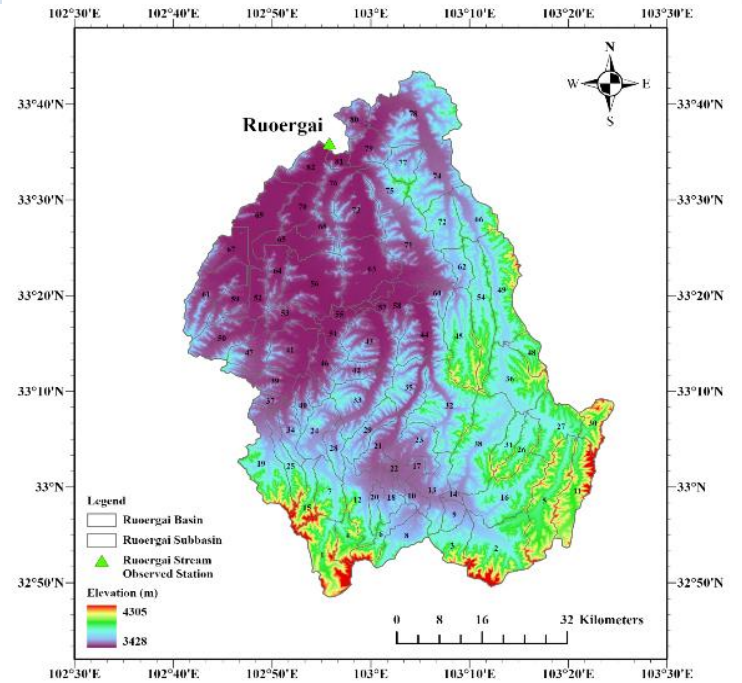
GOF criteria (R, RMSE, NRMSE, MB, NSE, and KGE) of simulated streamflow versus observed one at different time scales from 1-day to 15-day and monthly during Hydrologic Year from 2007 Oct 1st to 2017 September 30th.

Time Scale	R	RMSE	Nrmse	MB	NSE	KGE
1d	0.69	41.97	1.80	0.28	-0.17	0.41
5d	0.74	36.60	1.57	0.28	0.05	0.48
10d	0.78	30.89	1.34	0.28	0.25	0.56
15d	0.80	27.22	1.20	0.28	0.37	0.60
MON	0.84	23.06	0.99	0.29	0.47	0.62



Physical geography and hydrological characteristics

- **Geographical location:** Located in the northeastern part of the Qinghai-Tibet Plateau, with a watershed control area of approximately 4,000 km²
- **Climatic characteristics：** high altitude (above 3400m), low temperature (0.7~1.1 Celsius Degree), long snow cover period (9 months), and poor thermal conditions
- **Elements of runoff：** Precipitation, snowmelt, and permafrost
- **Observation stations**: the Joraga Hydrological Station and the Maowa Meteorological Station.



Data Type	Data Sources
Precipitation, Temperature, RH, Solar Radiation, Wind Speed	CMFD 2.0
ET, Runoff	Hydrologic Records
Snowmelt	AVHRR China Snow Phenomenon Dataset（1980-2020）

Results Analysis

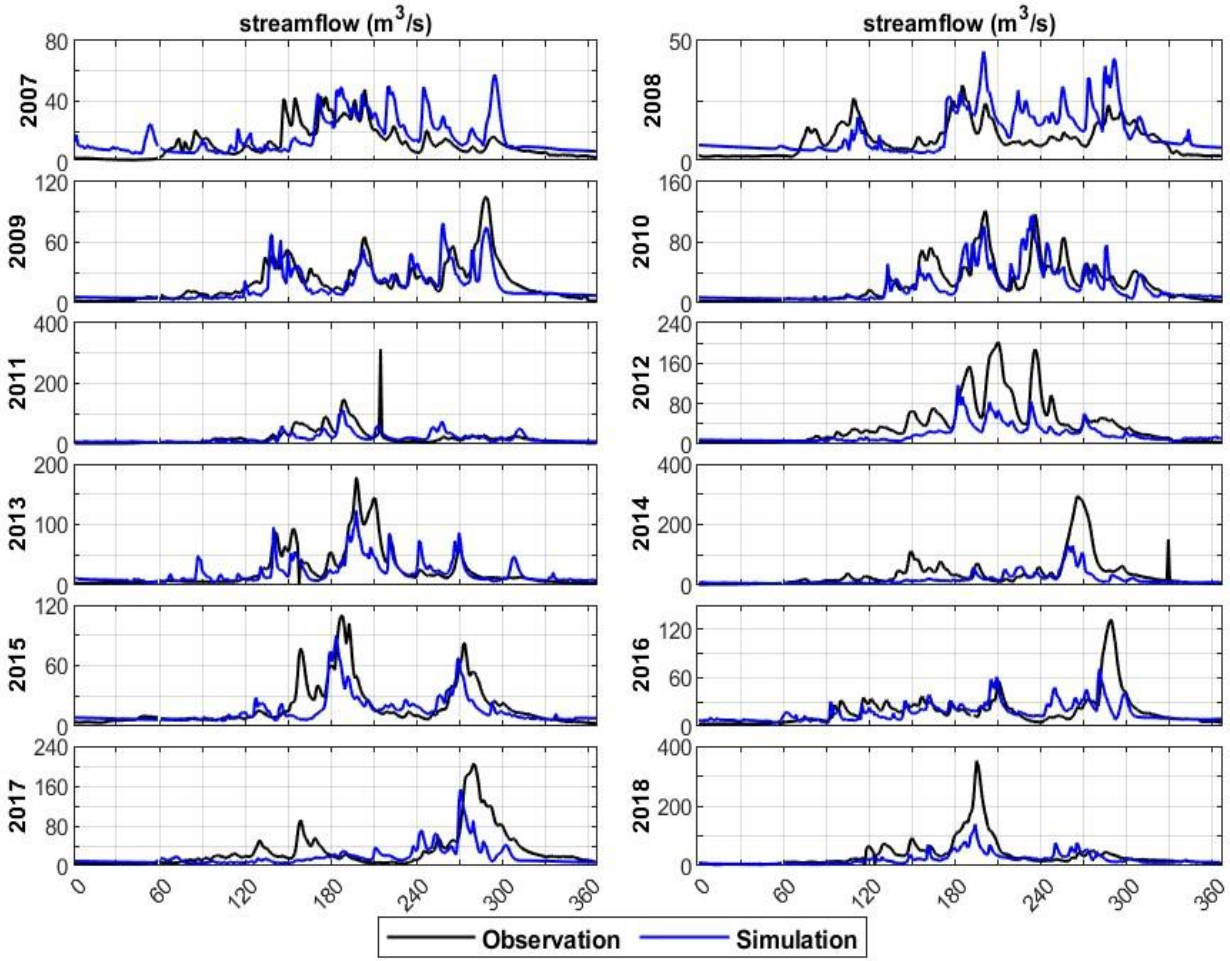


Figure 1: Daily time series of simulated streamflow versus the observed streamflow in each year during Jan-1s to Dec-31st.

Time Scale	R	RMSE	Nrmse	MB	NSE	KGE
1d	0.69	25.35	1.05	-0.25	0.41	0.40
5d	0.73	23.85	0.99	-0.25	0.45	0.41
10d	0.77	22.31	0.94	-0.25	0.48	0.42
15d	0.79	20.75	0.88	-0.25	0.50	0.43
MON	0.80	600.72	0.82	-0.25	0.49	0.41

GOF criteria (R, RMSE, NRMSE, MB, NSE, and KGE) of simulated streamflow versus observed one at different time scales from 1-day to 15-day and monthly during Jan-1st-2007 to Dec-31st-2018.

Cold Region Xin’anjiang Model Construction

- **Coupled Xin’anjiang Model with snowmelt module and soil freeze-thaw module.**
- **Input daily precipitation and temperature data into snowmelt module. Separate snow-water and snow accumulation to obtain total liquid water volume.**
- **Use the soil freeze-thaw module to calculate free water and tension water in each layer, calculate the frozen and unfrozen parts of the water storage capacity.**

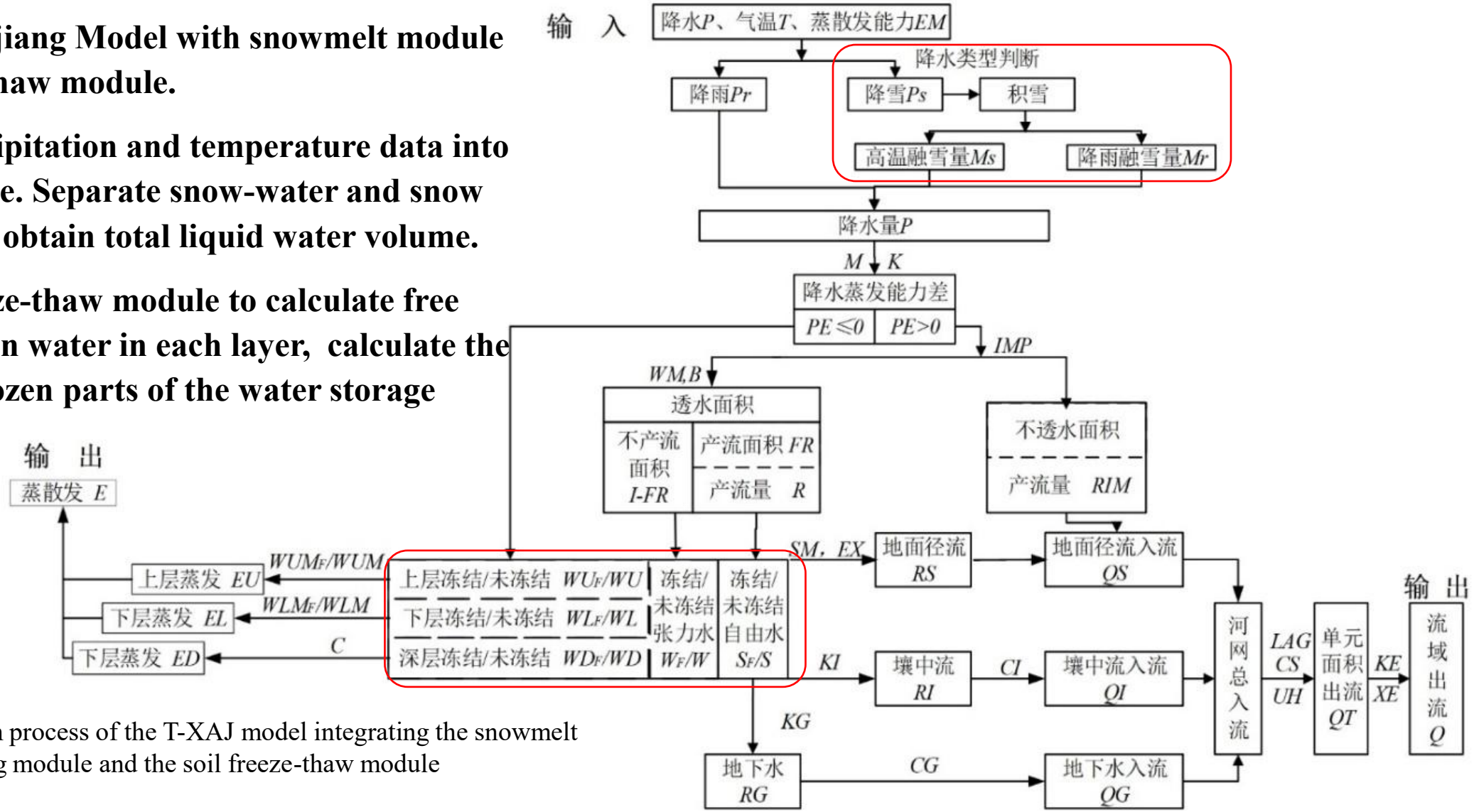
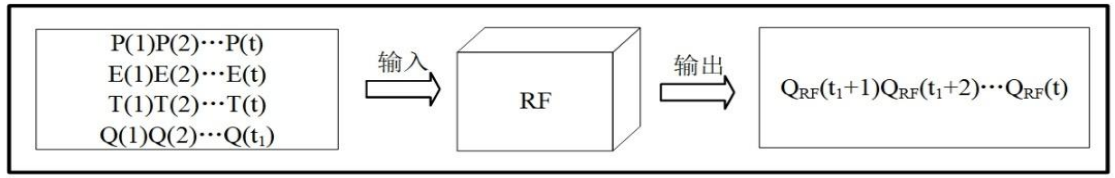


Figure: Construction process of the T-XAJ model integrating the snowmelt coupling module and the soil freeze-thaw module

Random Forest (RF) and Coupled T-XAJ-RF model Construction

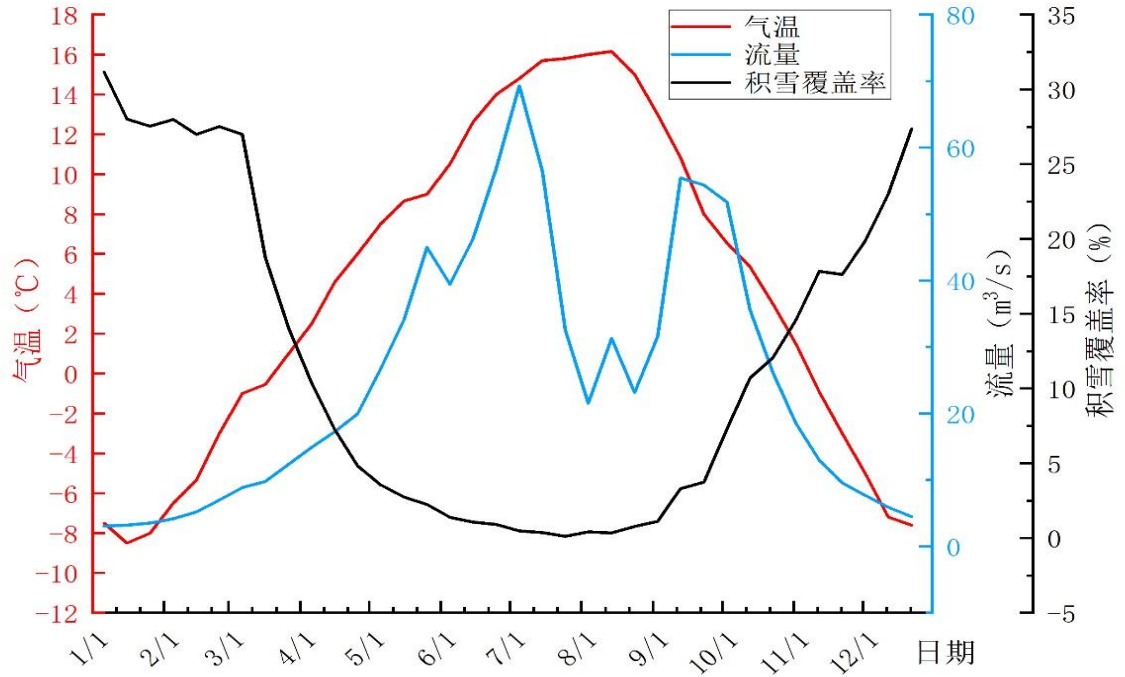
① RF模型



② T-XAJ-RF模型

- **RF Model：Random Forest model was constructed using regular precipitation, evaporation, air temperature and measured runoff. The precipitation, evaporation and air temperature during the validation period were input to simulate the streamflow**
- **T-XAJ-RF Model:**
  - **Phase One: Conduct full-period runoff simulation using the T-XAJ model using prec, ET and temperature as input, and output the streamflow and intermediate variables, including snowmelt volume and soil moisture content**
  - **Phase Two: Use regular prec, ET, air temperature, snowmelt volume, soil moisture content, simulated streamflow rate and measured streamflow rate to train RF model . Then use the trained T-XJA-RF model to predict the streamflow in the validation period using prec, ET, air temperature, snowmelt volume, soil moisture content and simulated flow rate.**

Runoff Periods

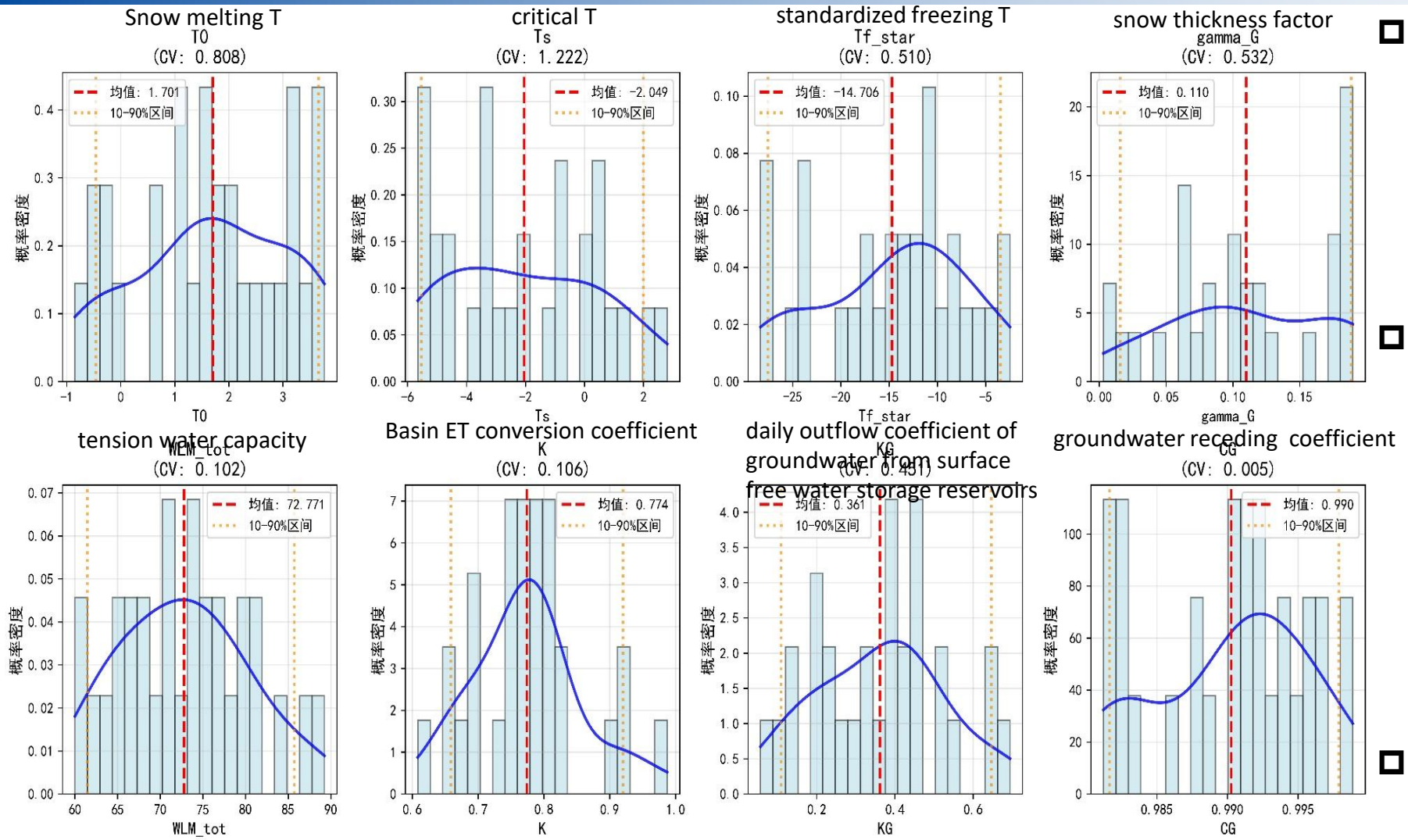


Dynamic variation chart of multi-year and ten-day averages of temperature, flow rate and snow coverage from 2007 to 2019

Period	Time Periods
Snow-Frozen Soil Thawing	Mar 6th-Jul 5th
Rainfall Runoff	Jul 6th –Oct 15th
Snow-Frozen Soil Receding	Oct 16th –Mar 5th (next year)

- **Divide the runoff process into three periods using K-means clustering method, combined the characteristics of temperature, runoff, snow cover and seasonal frozen soil in the study area: snow-frozen soil thawing, rainfall runoff, and snow-frozen soil receding period.**
- **The melting period of snow cover and frozen soil begins in spring. When the temperature reaches above zero degrees, the snow coverage rate gradually decreases. At this time, snow melting, frozen soil and precipitation jointly affect runoff. By mid-June, all the snow had melted, and by early July, the frozen soil had completely thawed. Precipitation became the main driving factor for the variation of runoff. In mid-October, the runoff decreased significantly, the snow accumulation was obvious, and the receding period of snow and frozen soil began.**

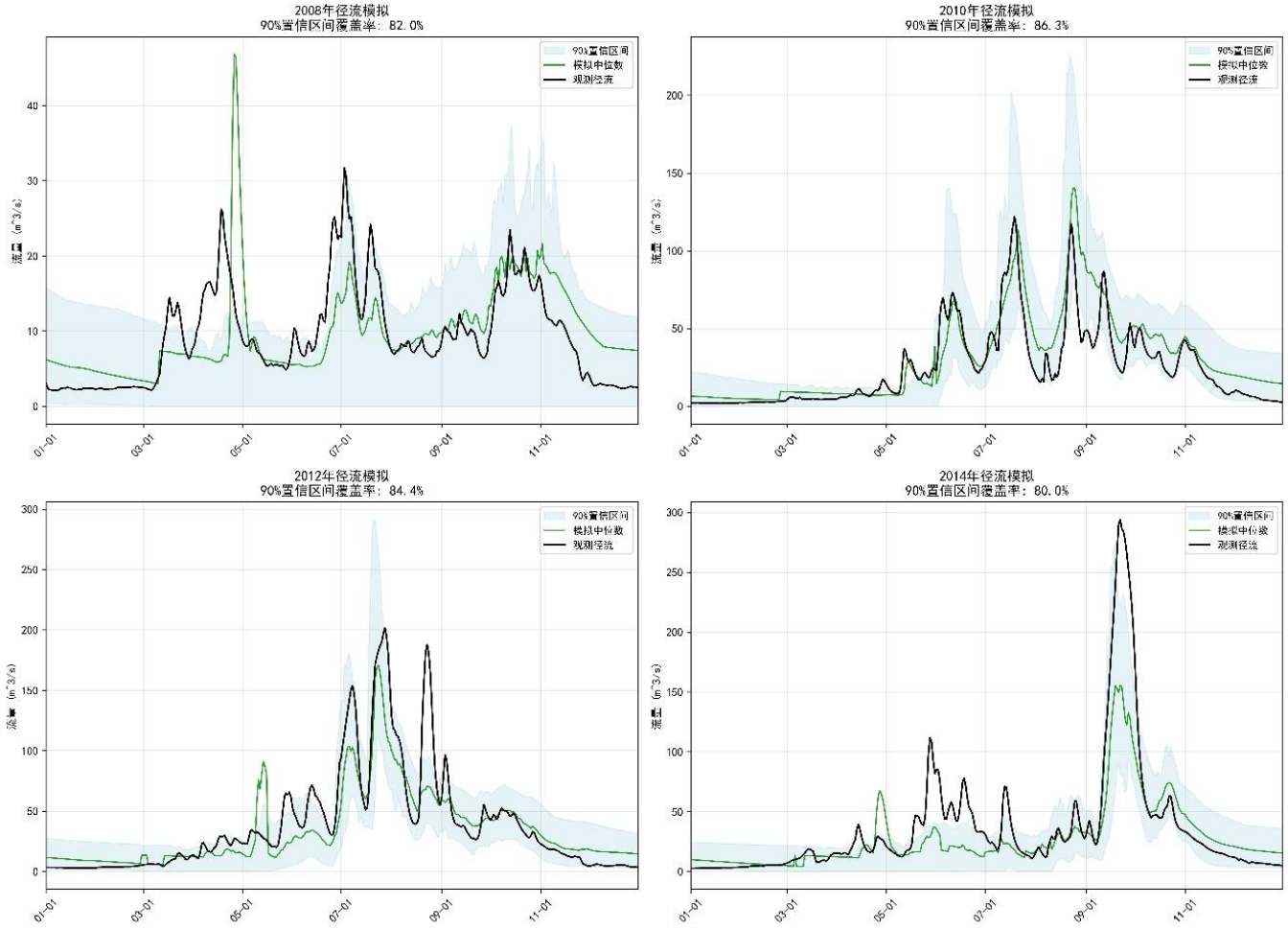
Results Analysis Uncertainty Analysis of T-XAJ Model



Posterior distribution plots of sensitive parameters

- **Based on the correlation degree between the parameters and the simulation result NSE, eight sensitive parameters (T0, Ts, Tf, γ, WLM, KC, KG and CG) in the T-XAJ model were selected for a post-distribution analysis.**
- **The distributions of T0 and Ts were dispersed and had the greatest uncertainty. The snow-melting module contributed the most to the uncertainty of the T-XAJ model, with a contribution rate of 22.9%. It is significantly higher than 9.6% of soil freeze-thaw module and 3.1% generated by module interaction**
- **Most parameters show a unimodal distribution, which has high identifiability and the overall robustness of the model is good**

Results Analysis: T-XAJ model uncertainties

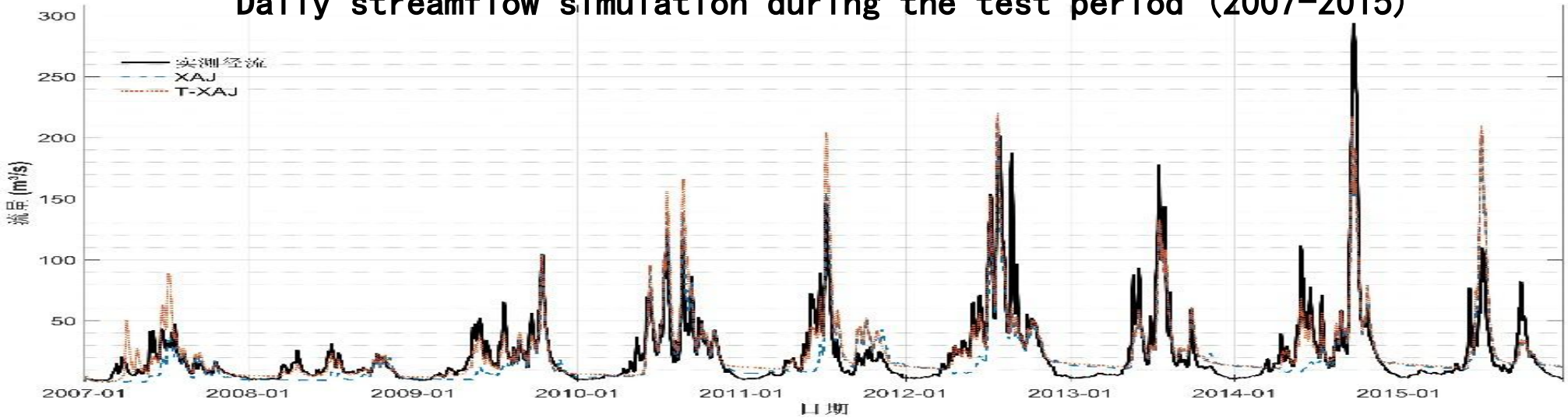


Runoff simulation performance in representative years

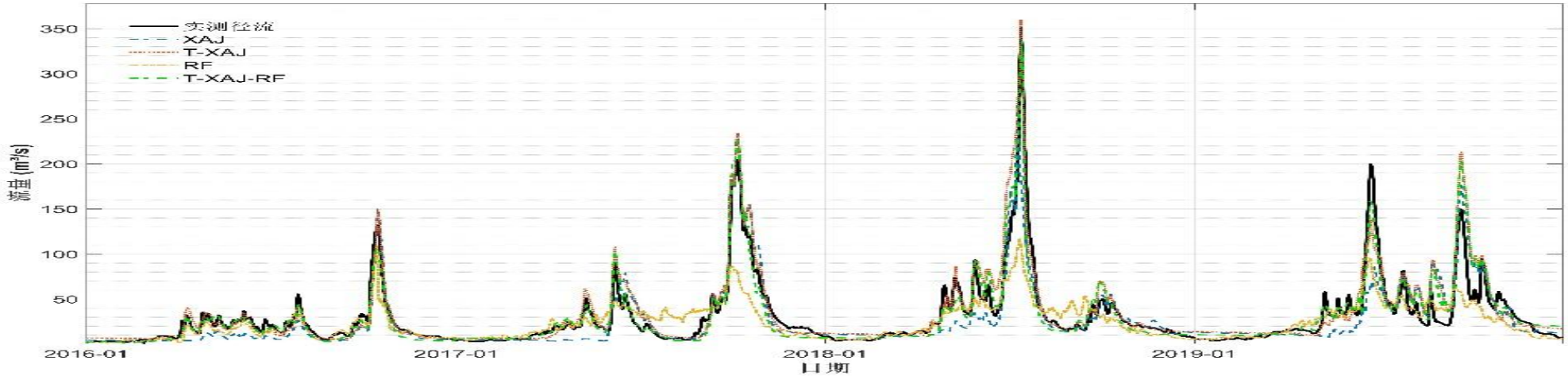
- Dry year (2008), Wet year (2014), and normal years (2010, 2012) were selected to evaluate the stability and reliability of the T-XAJ model under different flow magnitudes.
- The 90 % confidence interval width of the simulations from the behavioral parameter set is moderate, indicating low model uncertainty and favorable stability.
- The coverage rates of observed runoff values within the 90 % confidence intervals of predictions for the four representative years all exceed 80 %, with an average coverage rate of 83.2 %. This suggests that the model performs well in simulating runoff of different magnitudes and possesses satisfactory reliability.

Model Performance Comparison: Test Period: 2007-2015; Validation Period: 2016-2019, among XAJ, T-XAJ, RF and T-XAJ-RF.

Daily streamflow simulation during the test period (2007-2015)



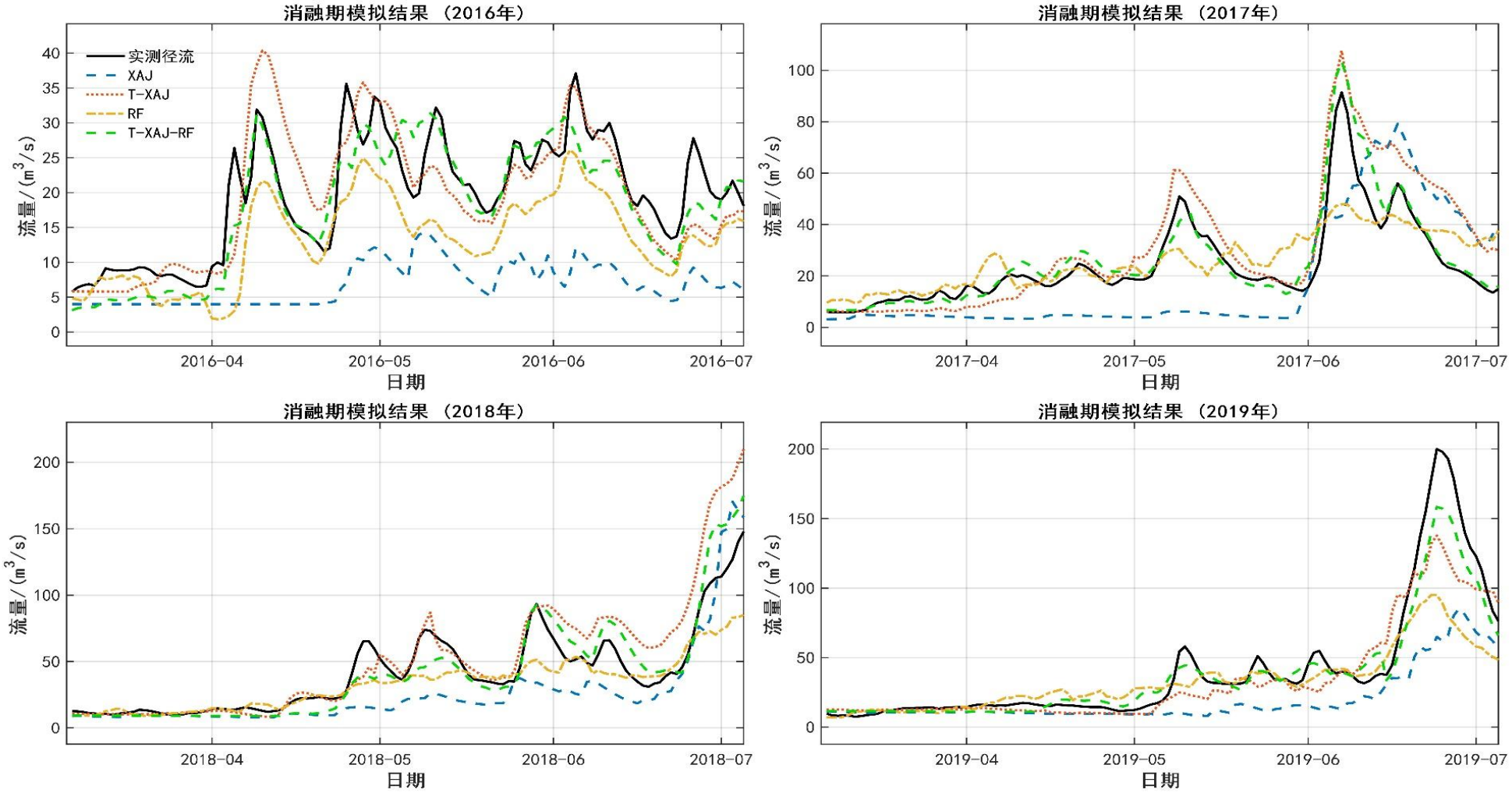
Daily streamflow simulation during the validation period (2016-2019)



Model Performance Comparison: Test Period: 2007-2015; Validation Period: 2016-2019, among XAJ, T-XAJ, RF and T-XAJ-RF.

Model	NSE	KGE	r	RMSE/(m^3/s)	Pbias/(%)
XAJ（2007- 2015）	0.67	0.77	0.83	17.44	-11.10
T-XAJ（2007- 2015）	0.74	0.83	0.87	15.71	10.20
XAJ（2016- 2019）	0.72	0.70	0.86	19.70	-13.30
T-XAJ（2016- 2019）	0.84	0.81	0.94	14.82	13.10
RF（2016- 2019）	0.57	0.45	0.84	24.70	-20.40
T-XAJ-RF(2016- 2019）	**0.90**	**0.94**	**0.95**	**11.90**	**-0.40**

Analysis of streamflow simulation results during the snow melting-soil thawing period



Comparison of streamflow simulation during the snow melting and soil thawing period during years 2016 to 2019 (March 6th - July 5th)

GOF Criteria during Melting Period

- Analysis of runoff simulation capabilities of different models during the snow and soil thawing peirod (March 6th - July 5th)

Year	Model	NSE	KGE	r	RMSE/(m^3/s)	Pbias/(%)
2016	XAJ	-1.95	0.04	0.74	14.33	-65.24
	T-XAJ	0.60	0.79	0.83	5.27	-1.91
	RF	0.16	0.57	0.86	7.65	-32.09
	T-XAJ-RF	**0.74**	**0.85**	**0.90**	**4.26**	**-8.88**
2017	XAJ	-0.27	0.42	0.64	18.78	-26.99
	T-XAJ	0.44	0.45	0.94	12.47	27.40
	RF	0.54	0.55	0.75	11.27	6.30
	T-XAJ-RF	**0.88**	**0.79**	**0.97**	**5.69**	**8.10**
2018	XAJ	0.43	0.60	0.84	23.09	-36.82
	T-XAJ	0.51	0.46	0.95	21.31	24.39
	RF	0.68	0.56	0.92	17.26	-19.53
	T-XAJ-RF	**0.83**	**0.75**	**0.96**	**12.57**	**-0.29**
2019	XAJ	0.37	0.22	0.91	35.30	-51.33
	T-XAJ	0.83	0.72	0.94	18.52	-15.43
	RF	0.60	0.42	0.91	28.23	-19.81
	T-XAJ-RF	**0.93**	**0.77**	**0.99**	**11.69**	**-8.17**

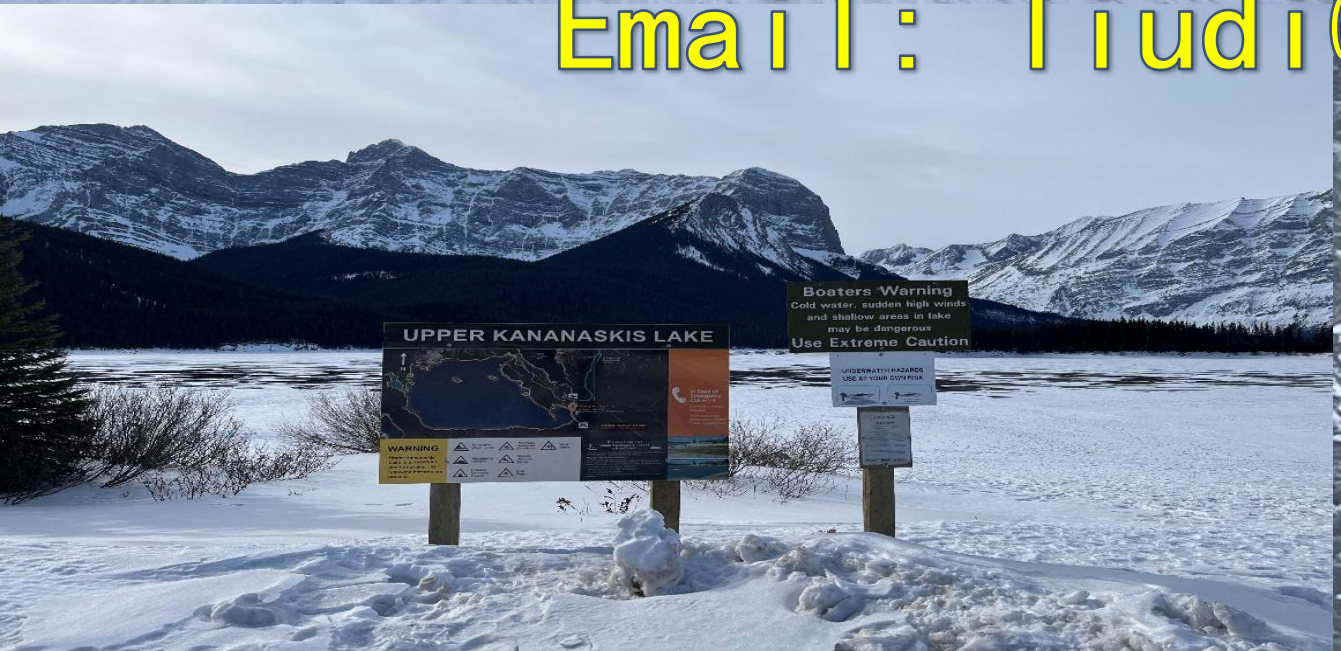
Conclusions

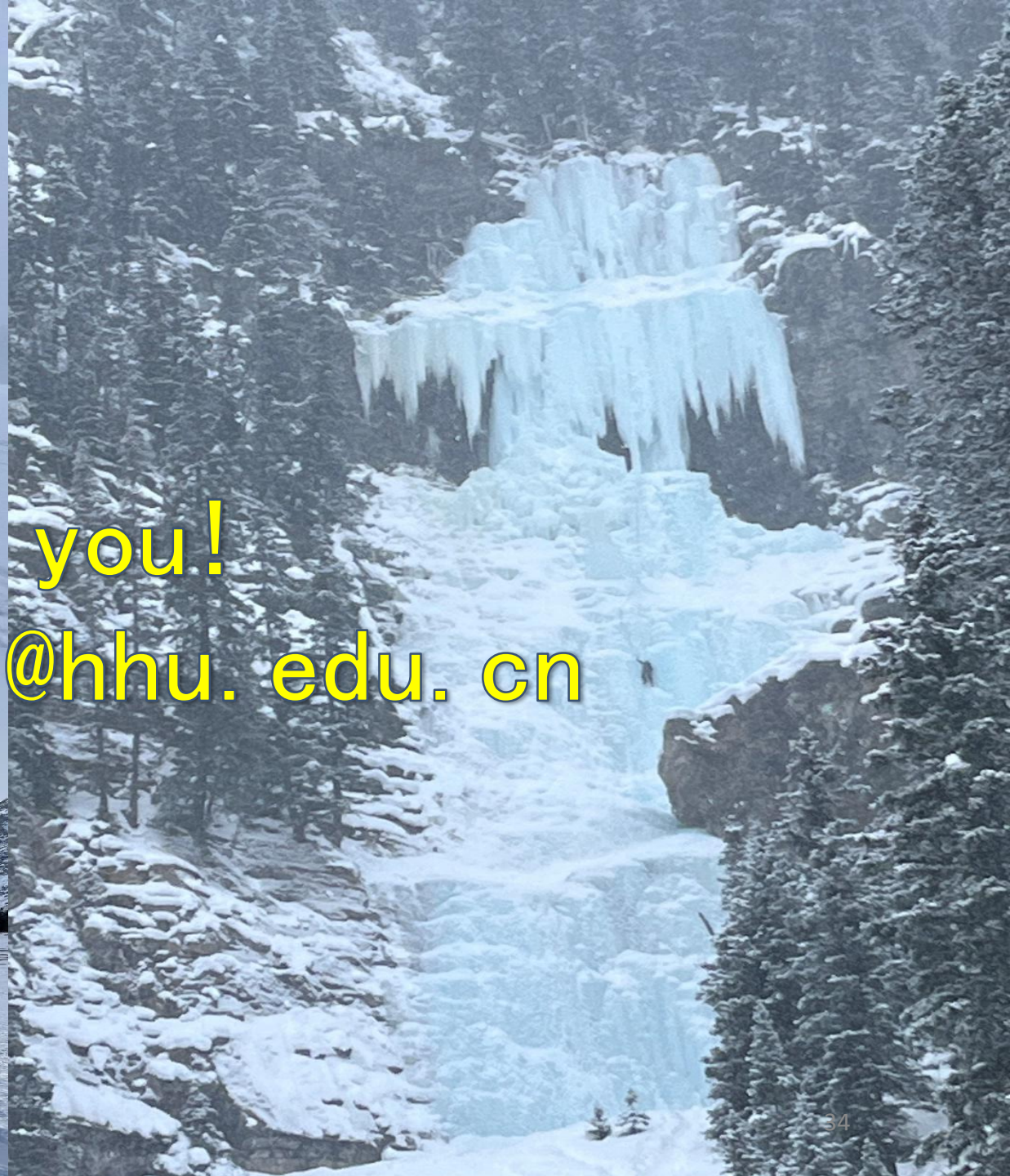
- Traditional Xinanjiang (XAJ) model suffers from severe deficiencies in simulation capability during the melting-thawing period, and its performance is inferior to other models.
- RF model can capture nonlinear characteristics of hydrological processes; however, it shows poor adaptability to extreme hydrological events and struggles to reproduce peak-flow dynamics. Its simulation performance in the validation period is worse than that of XAJ model.
- T-XAJ model exhibits a 35.6 % increase in uncertainty relative to XAJ model, but maintains favorable reliability and stability, with performance comparable to RF model during melting-thawing period. In validation period, its NSE increases by 0.12 and 0.27, and KGE rises by 0.11 and 0.36 compared with the XAJ and RF models respectively, indicating improved simulation performance.
- T-XAJ-RF model yields generally enhanced simulation metrics for both melting-thawing period and the entire validation period. NSE and KGE exceed 0.70 in melting-thawing period; overall NSE, KGE and correlation coefficient r are all above 0.90 in validation period, while percentage bias falls within ±10 %. It achieves superior simulation accuracy and stability, demonstrating that intelligent hydrological models integrating physical mechanisms and data-driven approaches are better suited for hydrological process simulation in alpine regions.

04 Following Work

Following Work

- With the advancement of big data and artificial intelligence technologies, current approaches to simulating hydrological processes in cold regions mainly follow two technical pathways.
  - One approach involves improving physically based models by incorporating modular techniques to refine hydrological physical processes. However, purely physics-based models still face limitations when dealing with complex nonlinear relationships.
  - The other approach employs data-driven methods to replace physical models for runoff simulation, which excel at capturing complex patterns but lack underlying physical mechanisms.
  - Effectively integrating hydrological physical mechanisms with machine learning algorithms to optimize data-driven models has become a key focus in the development of intelligent water management systems for cold regions.





Thank you!

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Related Publications

- Liu Di, Sun Jiaqian, ZhongboYu*, Haishen Lü, Yonghua Zhu. An aggregation framework to diagnose the compound hydroclimatic change of the Tibetan Plateau using multiple reanalysis data. Journal of Hydrology: Regional Studies, 2024 Jun, 53, 101746
- Liu Di, ZhongboYu*, Haishen Lü, Huanghe Gu, Chuanguo Yang, Qin Ju, Jiaqian Sun, Xiaolei Fu. Diagnosing the compound seasonal soil moisture-hydroclimate interaction regime on the Tibetan Plateau using multi-high-resolution reanalysis products and one regional climate model. Journal of Hydrology, 2023 May, 620(B): 129517.
- Liu Di, Ashok K. Mishra*, ZhongboYu*, Haishen Lü, Yajie Li. Support vector machine and data assimilation framework for Groundwater Level Forecasting using GRACE satellite data. Journal of Hydrology, 2021 Dec, 603: 126929.
- Liu Di, Ashok K. Mishra*, Deepak K. Ray. Sensitivity of global major crop yields to climate variables: A non-parametric elasticity analysis. Science of the Total Environment, 2020 Dec 15, 748: 141431.
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- Yu, Zhongbo, Liu, Di, Lü, Haishen, Fu, Xiaolei, Xiang, Long, Zhu, Yonghua, A multi-layer soil moisture data assimilation using support vector machines and ensemble particle filter, Journal of Hydrology, 2012 Dec 19, 475: 53~64.
- 刘娣, 董兆龙, 吕海深, 张展, 朱永华, 鞠琴，余钟波., 2026. 高寒区耦合融雪冻土机器学习的新安江模型径流模拟. *水资源保护*