

Supporting Information for

Antagonism or synergy: Divergent surface water dynamics at the southern margin of the Eurasian permafrost

Bo Zhang¹, Tiantian Liao¹, Haitian Lu², Jianuo Li¹, Ziyang Huang¹, Jiuhui Li^{1*}, Meng Guo^{1*}

¹Key Laboratory of Geographical Processes and Ecological Security of Changbai Mountains, Ministry of Education, School of Geographical Sciences, Northeast Normal University, Changchun, 130024, China

²School of Architecture and Urban Planning, Chongqing University, Chongqing, 400045, China

Correspondence to: Jiuhui Li (lijh801@nenu.edu.cn) and Meng Guo (guom521@nenu.edu.cn)

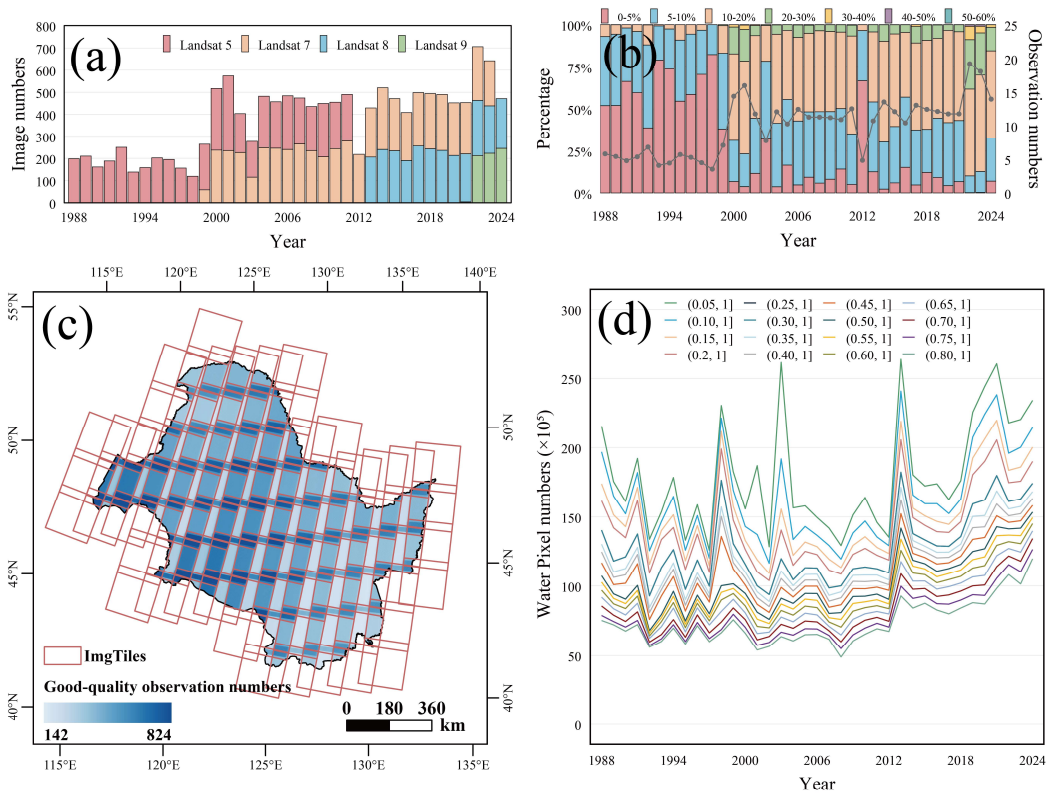


Figure S1. Analysis of Landsat image availability in the SHRZ from 1988 to 2024. (a) The number of high-quality Landsat images; (b) The quantitative distribution and annual mean of high-quality pixel observation counts and their proportion; (c) The spatial distribution of multi-year mean high-quality pixel observation counts; (d) The quantitative distribution of pixels across different water frequency ranges. (The standard administrative division data of China is from the National Platform for Common Geospatial Information Services, map approval number:

GS (2024) 0650).

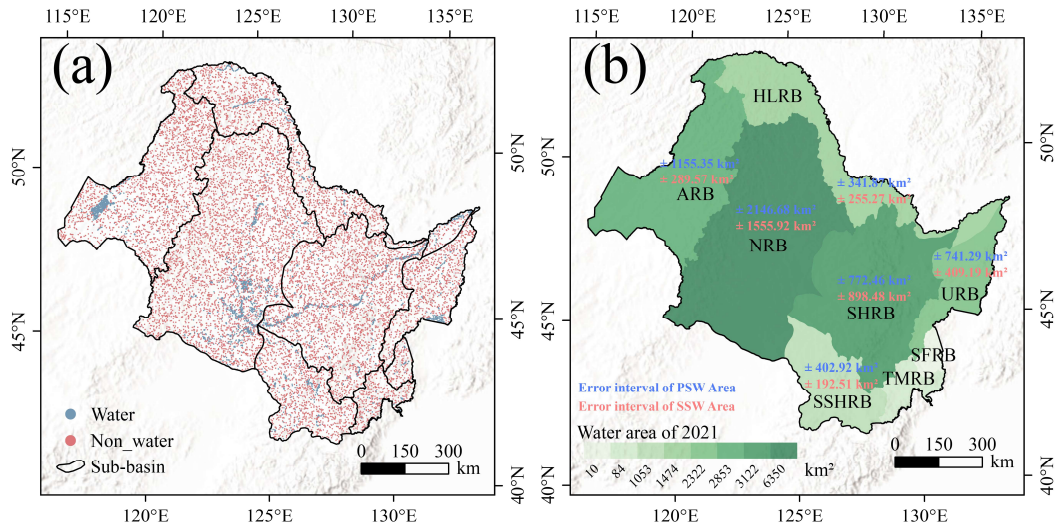


Figure S2. Surface water sampling design and validation results in 2021. (a) Stratified sampling design; (b) Validation results from the area estimation adjustment error method. Following the national water resources zones classification, the SHRZ comprises eight secondary river basins: Nen river basin (NRB), Songhua river basin (SHRB), Argun river basin (ARB), Heilong river basin (HLRB), Second Songhua river basin (SSHRB), Ussuri river basin (URB), Tumen river basin (TMRB), and Suifen river basin (SFRB).

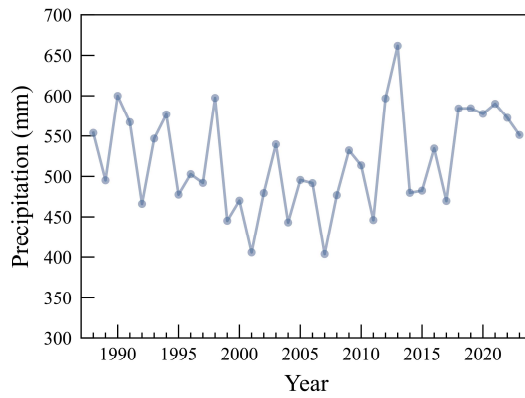


Figure S3. Mean annual precipitation in the SHRZ from 1988 to 2024.

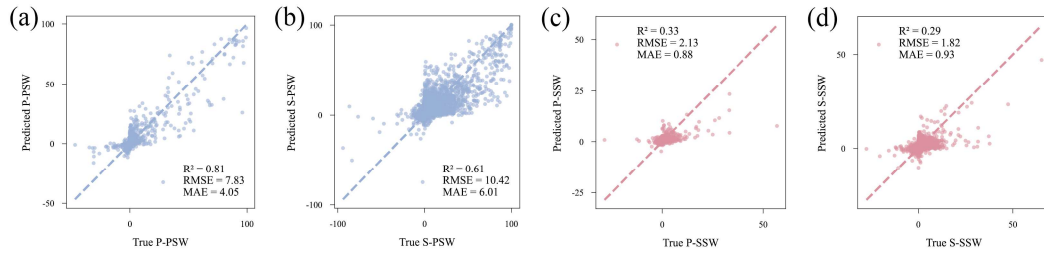


Figure S4. Model performance evaluation. (a–d) Scatter plots comparing predicted versus observed values for P-PSW, S-PSW, P-SSW, and S-SSW, with accuracy metrics embedded, the dashed line indicates the 1:1 relationship.

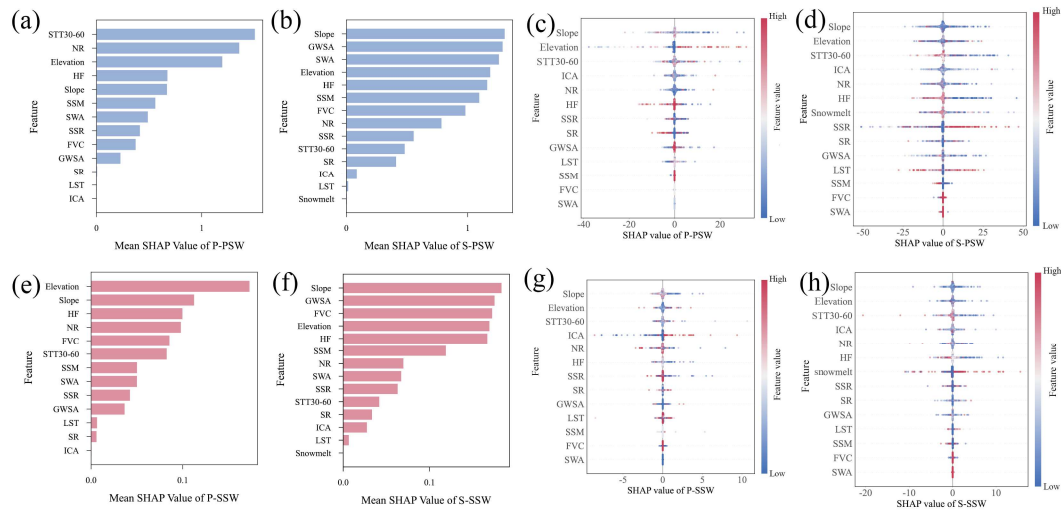


Figure S5. Global SHAP attribution analysis for PSW and SSW. (a–b) Global importance rankings based on mean absolute SHAP values for PSW in the permafrost and seasonal frozen ground regions, respectively; (c–d) SHAP summary plots illustrating the distribution and direction of feature impacts for PSW in the corresponding regions; (e–f) Global SHAP importance rankings for SSW in the permafrost and seasonally frozen ground regions; (g–h) SHAP summary plots illustrating the distribution of feature impacts for SSW in the corresponding regions. ‘P-’ presents the permafrost region, ‘S-’ presents the seasonal frozen ground region.

Table S1 Stratified random sample point design in the SHRZ.

Samples	HL	ARB	SHRB	NRB	URB	SSH	SFRB	TMRB	Total
	RB					RB			
Water	386	509	615	946	194	242	34	74	3000
Non-water	1546	2035	2460	3784	774	968	136	297	12000
Total samples	1932	2544	3075	4730	968	1210	170	371	15000
Area (km ²)	119065	156776	189530	291474	59659	74562	10452	22881	924403

Table S2 Confusion matrix for accuracy assessment of original method in the SHRZ in 2021.

Samples	Ground verification		Total	User's accuracy
	Water	Non-water		
Water	2075	925	3000	69.17%
Non-water	583	11417	12000	95.14%
Producer's accuracy	21.33%	99.39%	/	Overall accuracy =94.66%

Table S3 Confusion matrix for accuracy assessment of IOWDM-ENC in the SHRZ in 2021.

Samples	Ground verification		Total	User's accuracy
	Water	Non-water		
Water	2859	141	3000	95.3%
Non-water	108	11916	12000	99.1%
Producer's accuracy	66.89%	99.91%	/	Overall accuracy =99.03%

Table S4 Confusion matrix for accuracy assessment of JRC-GSW in the SHRZ in 2021.

Samples	Ground verification		Total	User's accuracy
	Water	Non-water		
Water	2542	458	3000	84.73%
Non-water	163	11837	12000	98.64%
Producer's accuracy	54.29%	99.71%	/	Overall accuracy =98.38%

Table S5 Changes in surface water frequency in the SHRZ from 1988 to 2024.

	Significant reduction	No-significant reduction	Significant increase	No-significant increase	SUM
Area (km ²)	792.09	479.59	3644.78	1049.39	5965.85
Percent (%)	13.28%	8.04%	61.09%	17.59%	100%

Table S6 Changes in surface water frequency between permafrost and Seasonal frozen ground regions from 1988 to 2024.

Permafrost type	Significant reduction	No-significant reduction	Significant increase	No-significant increase	Overall significant trend
Permafrost	5.00%	5.24%	13.53%	6.08%	8.53%
Seasonal frozen ground	4.93%	2.35%	25.37%	6.68%	20.44%