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Achieving water budget closure through physical hydrological process modelling: insights from a large-sample study

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Table S1. Summary of the 18 excluded basins, including the id, location, area and excluded reasons.

HRU ID	Lat	Lon	Area (km^2)	Excluded reason
01118300	41.49	-71.84	13.71	Data is missing between 1998 and 2010
01121000	41.87	-72.17	94.70	Data is missing between 1998 and 2010
01187300	42.08	-72.98	54.22	Data is missing between 1998 and 2010
01510000	42.69	-75.81	382.93	Data is missing between 1998 and 2010
02125000	35.39	-80.35	145.08	Incomplete observation in 2010
02202600	32.28	-81.63	623.35	Data is missing between 1998 and 2010
03281100	37.05	-83.75	425.26	Data is missing between 1998 and 2010
03300400	37.76	-85.07	1128.56	Data is missing between 1998 and 2010
05062500	47.29	-95.74	2435.96	Data is missing between 1998 and 2010
06154410	47.96	-108.63	47.72	No observation in 2010
06291500	45.04	-107.74	220.73	No observation in 2010
07290650	31.94	-90.55	1694.64	Data is missing between 1998 and 2010
07295000	31.17	-91.18	466.89	Data is missing between 1998 and 2010
08079600	33.24	-101.86	3512.32	Data is missing between 1998 and 2010
09497800	34.04	-110.51	751.79	Data is missing between 1998 and 2010
10173450	37.63	-112.69	281.69	Data is missing between 1998 and 2010
12383500	47.14	-113.92	17.70	Incomplete observation in 2010
12388400	47.24	-114.40	76.56	Incomplete observation in 2010

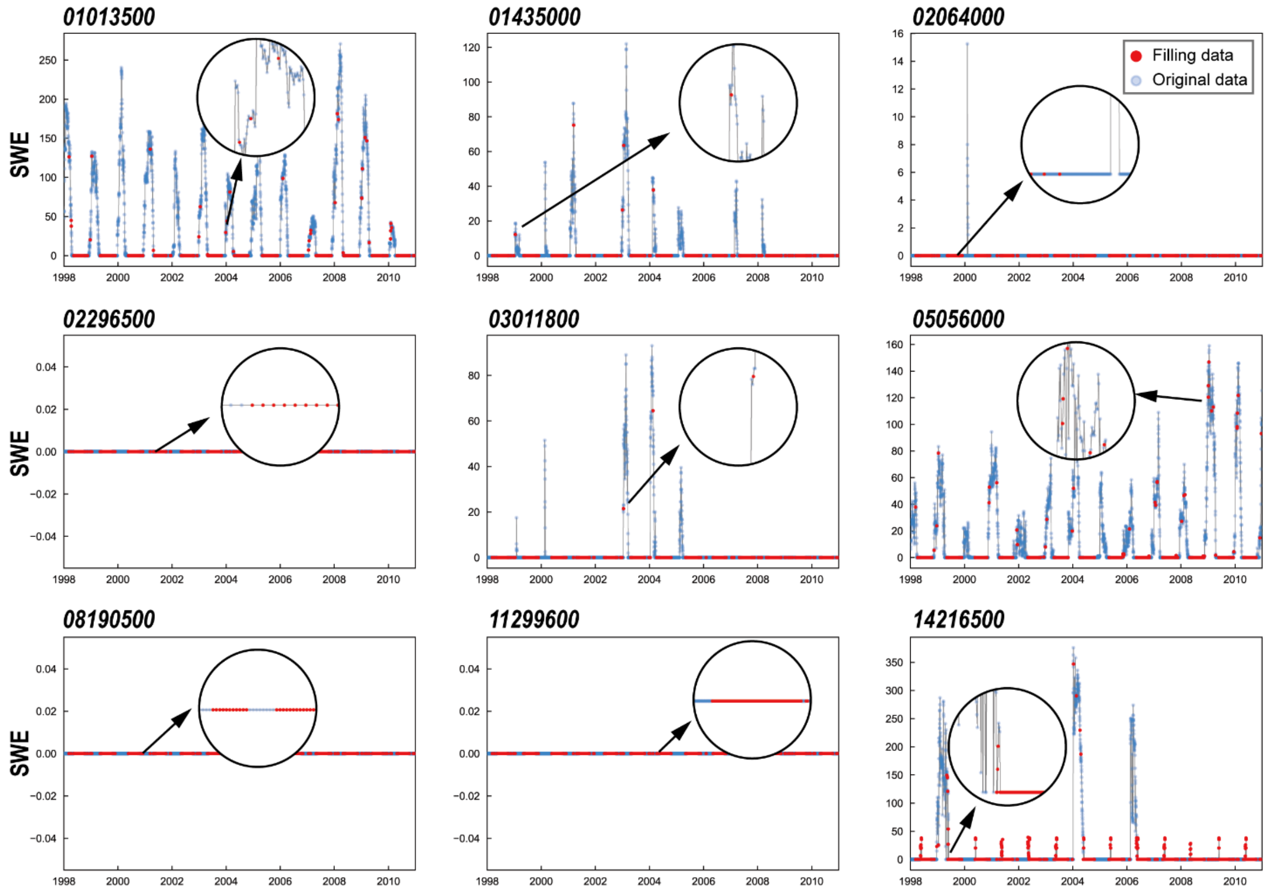


Figure S1. Schematic diagram of the gap filling process for GlobSnow SWE at nine randomly selected basins.

Table S2. Summary of the parameters settings in the PHPM-MDCF.

Parameters	Reference value	Reference range	Description
r_0	0.5	0.3~0.6	Initial correction rate.
Decay approach	Multiplicative	Linear, exponential, and multiplicative decay	The method of reduction in correction rate following an unreliable simulation.
Δr	50%	30%~70%	Decay rate of the correction rate.
Res_t	10%	5%~20%	Correction termination threshold for inconsistency residuals.
r_t	4%	1%~10%	Correction termination threshold for correction rate.

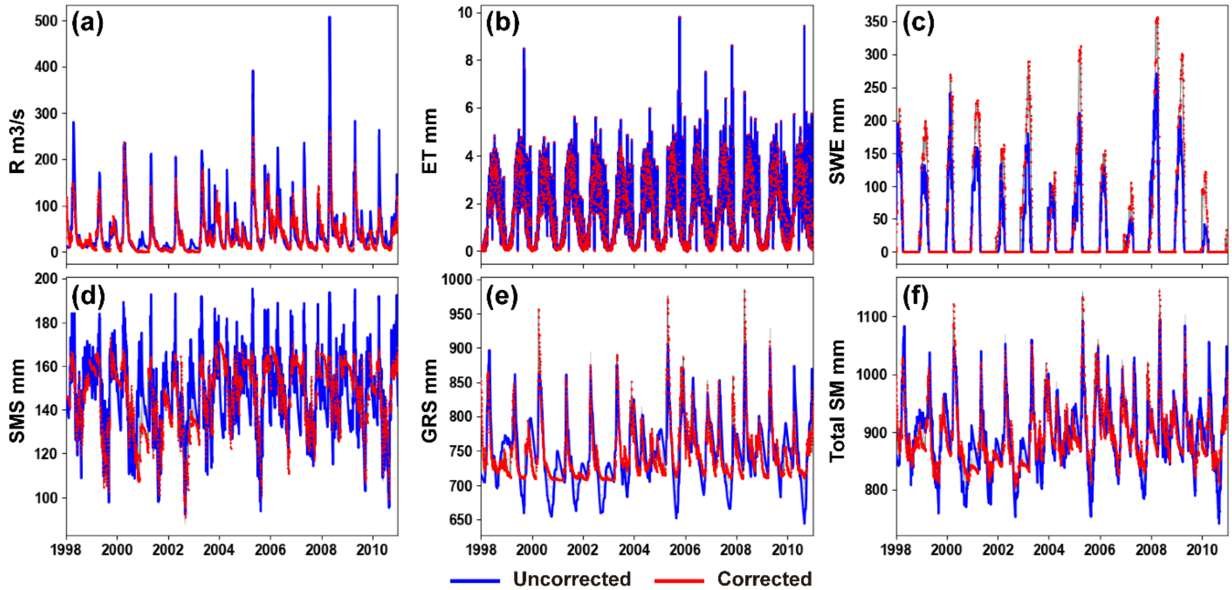


Figure S2. Time series of water budget variables before and after correction at basin 1013500. Note the total SM is the combination of SMS and GRS.

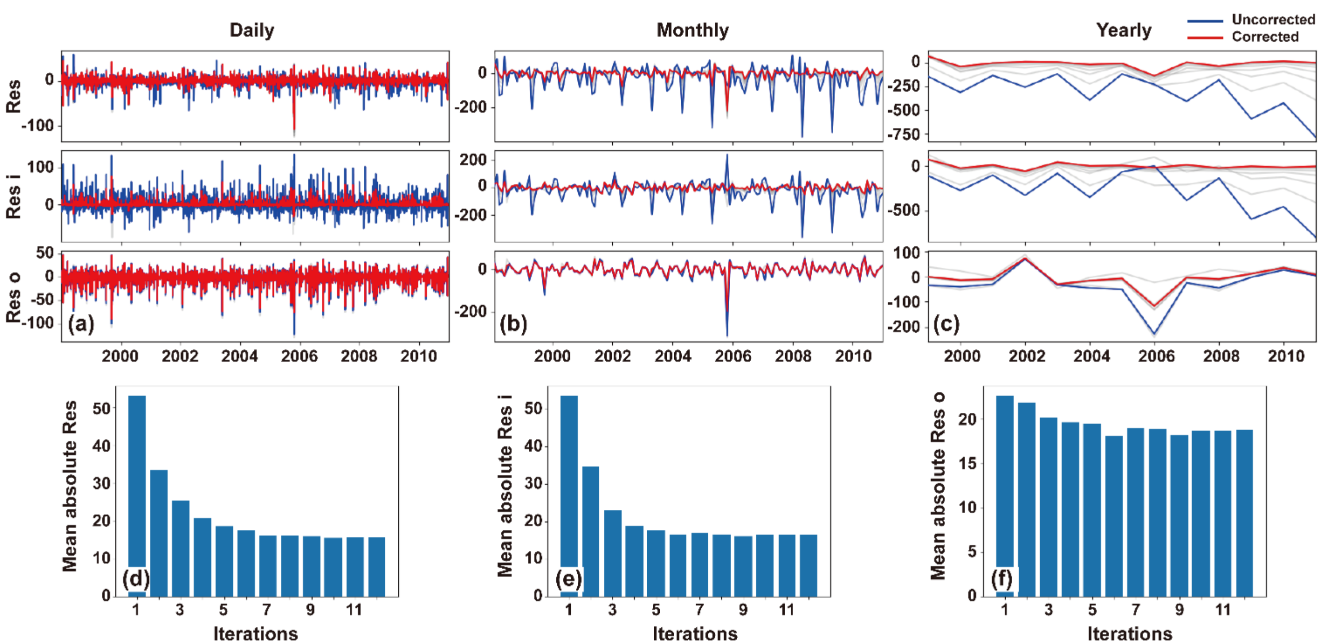


Figure S3. Same as Fig. 6, but for basin 1137500.

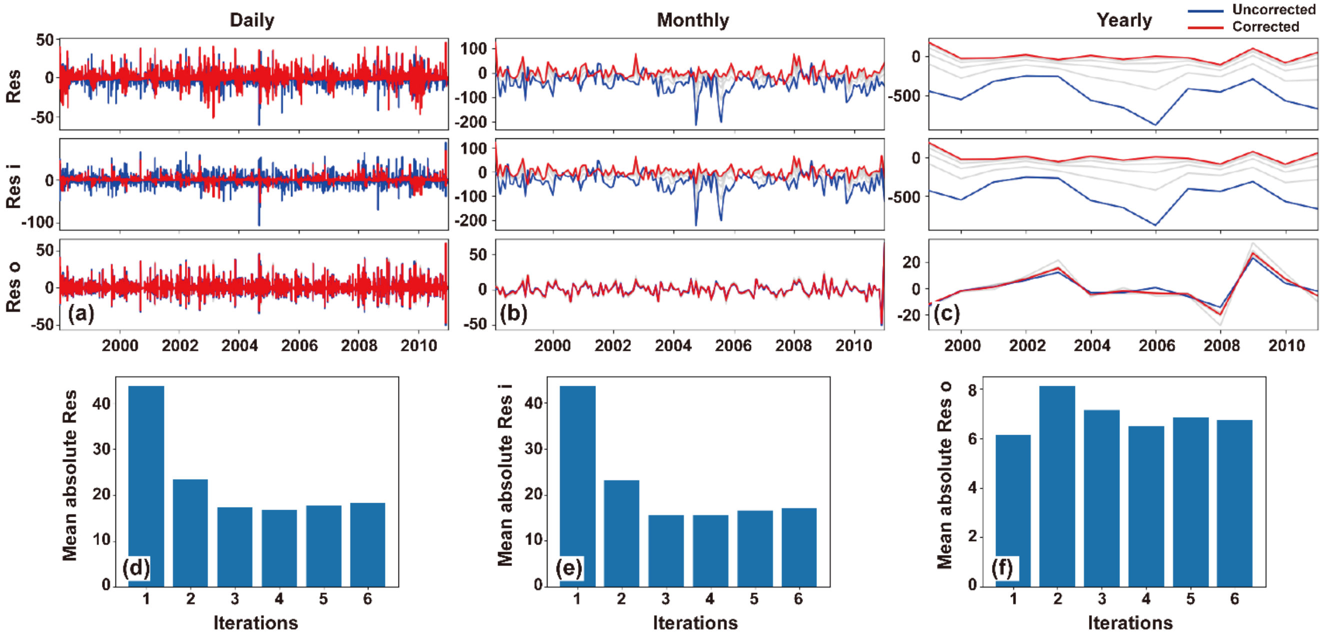


Figure S4. Same as Fig. 6, but for basin 2177000.

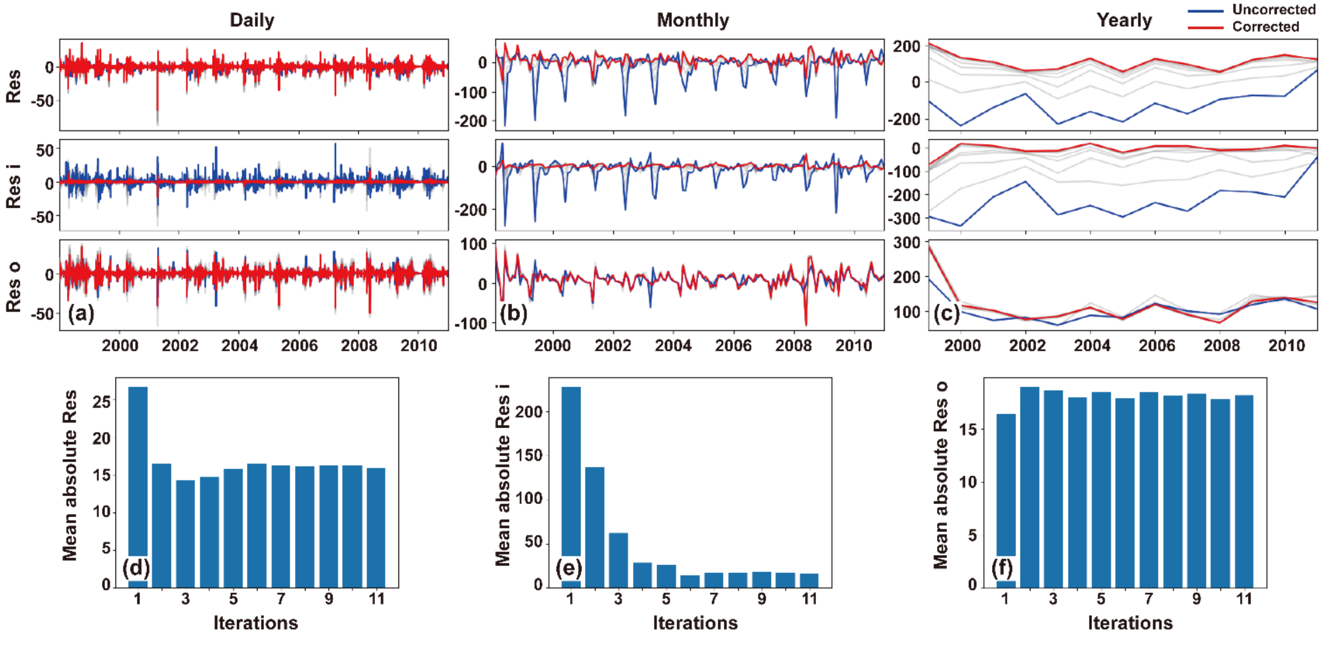


Figure S5. Same as Fig. 6, but for basin 6311000.

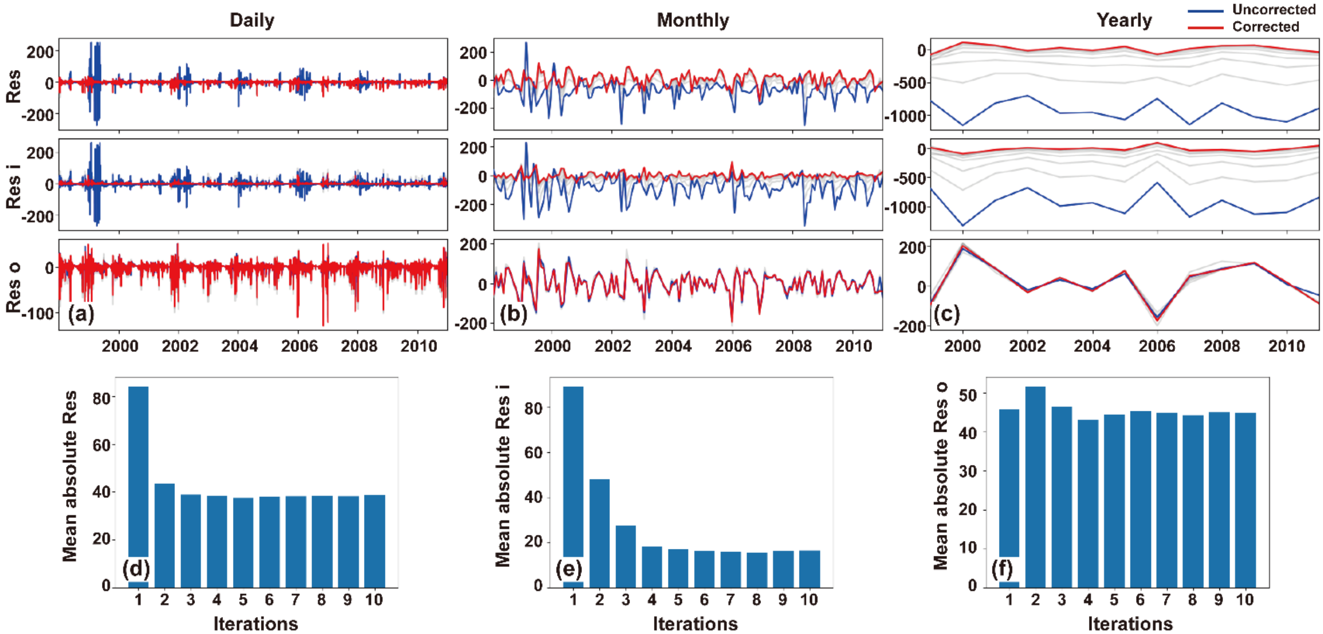


Figure S6. Same as Fig. 6, but for basin 14092750.

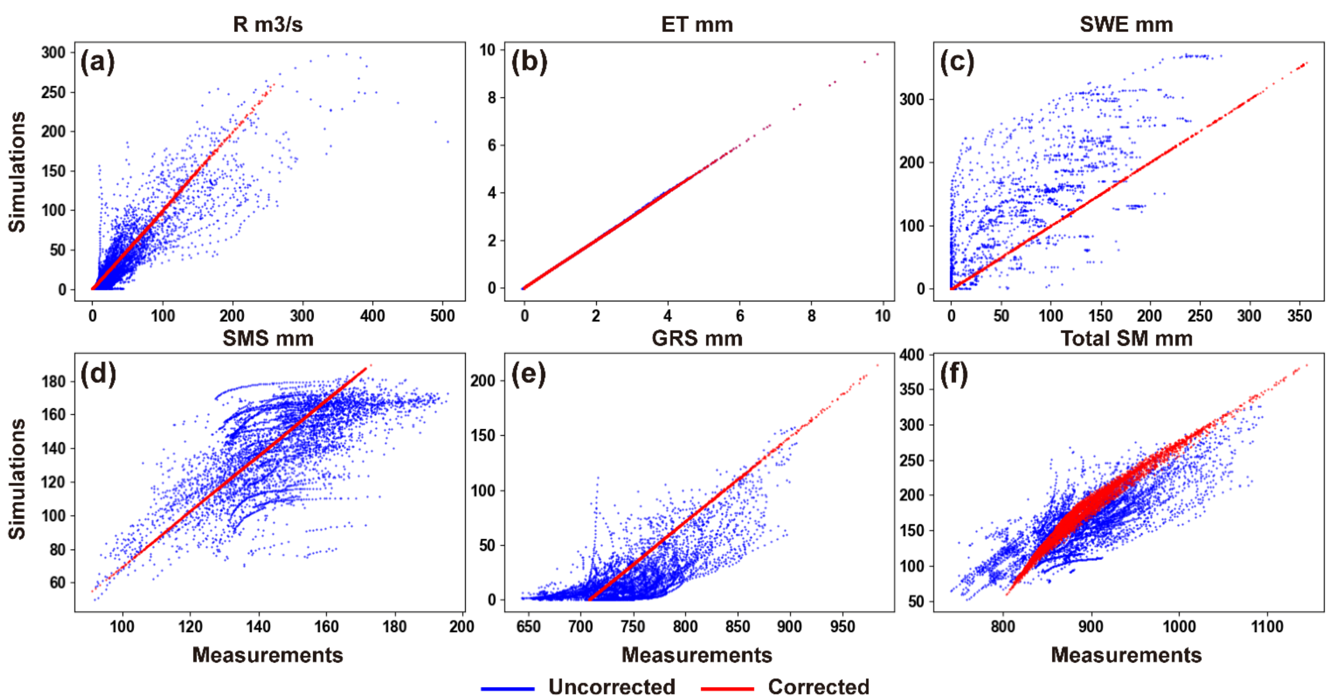


Figure S7. Scatter plots comparing measurements and simulation before and after correction at basin 1013500.

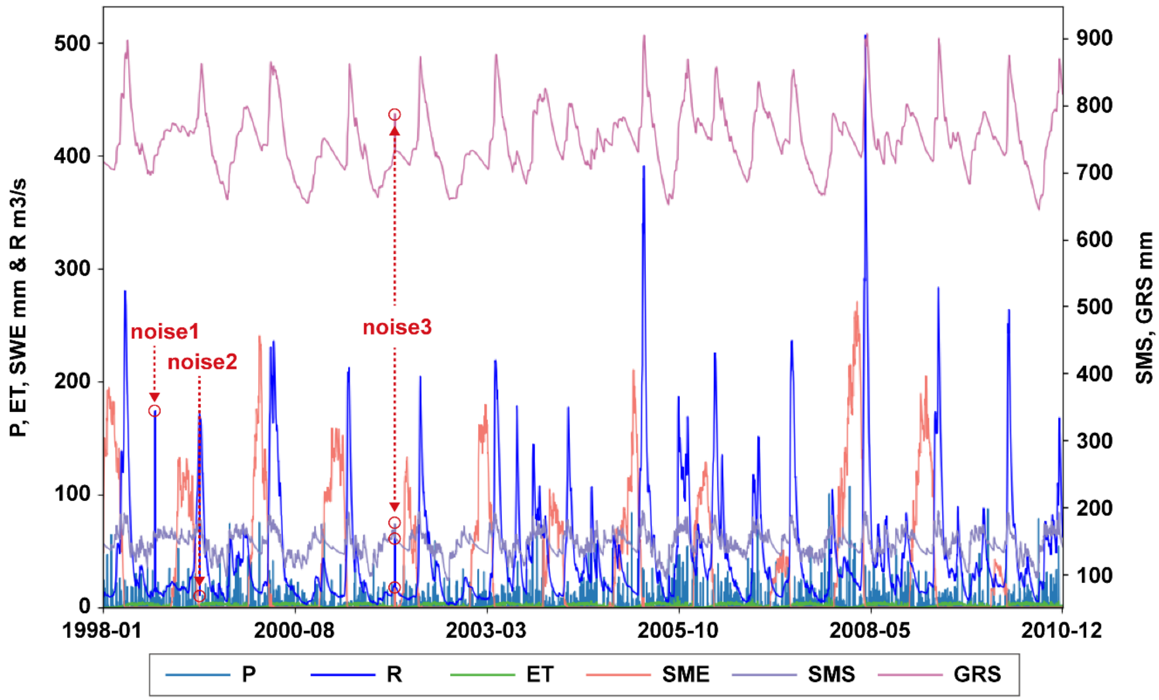


Figure S8. Noise sequence (NS1) generated by adding three single-point noises, corresponds to noise experiments 1-3.

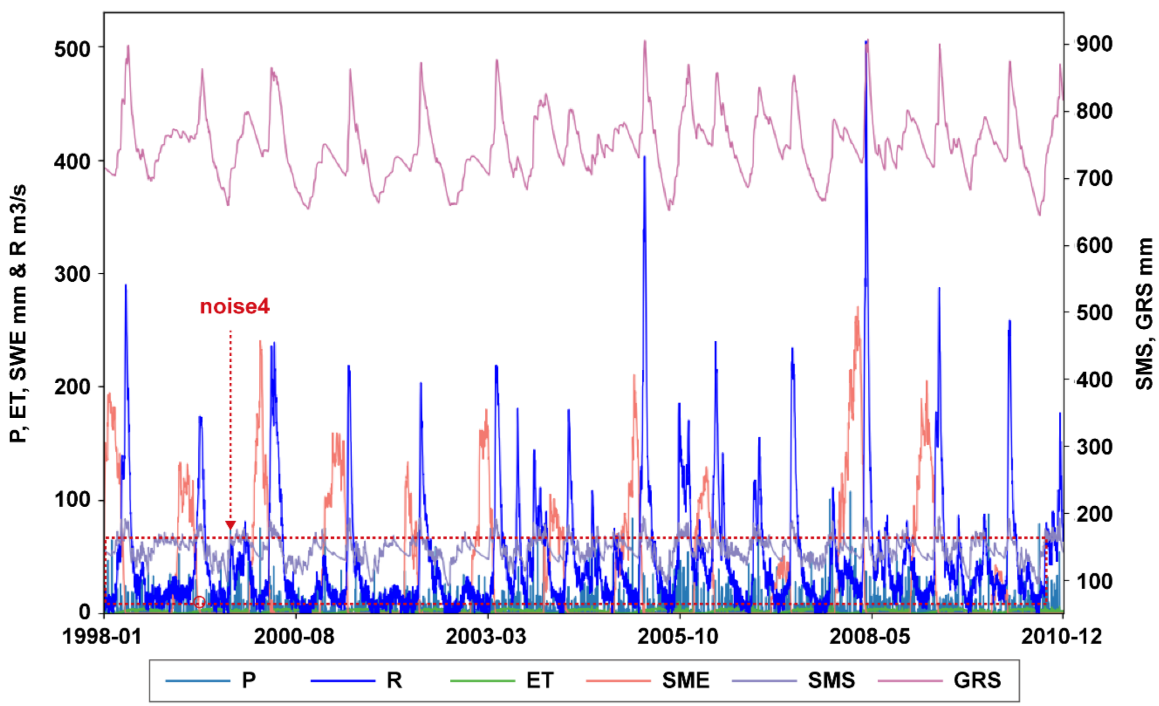


Figure S9. Noise sequence (NS2) generated by adding a Gaussian white noise sequence into the runoff, corresponds to noise experiment 4.

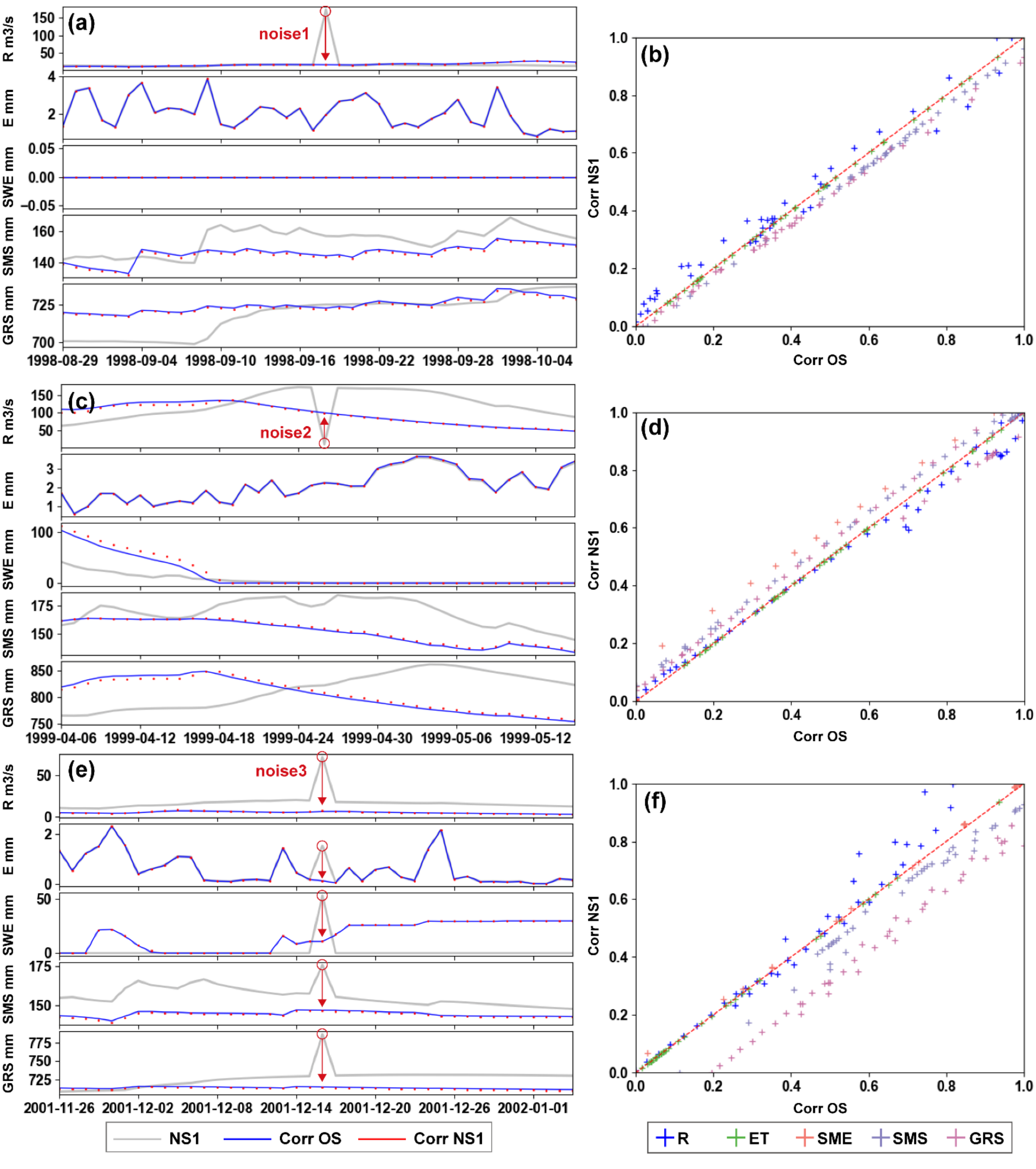


Figure S10. Correction results for multisource datasets around noises 1-3. Panels in the left column depict the time series of OS-based and NS1-based correction (Corr OS and Corr NS1), while panels in the right column compare them in terms of standardized values.

Table S3. Summary of datasets from Lehmann et al. (2022).

Variable	Product	Original Resolution		Original Period
		Spatial	Temporal	
Precipitation	CPC	0.5°×0.5°	Monthly	2002-2017
	CRU	0.5°×0.5°	Monthly	1901-2019
	ERA5 Land	0.1°×0.1°	Monthly	1981-2020
	PGF	1.0°×1.0°	Monthly	1948-2014
	GPCC	0.5°×0.5°	Monthly	1891-2016
	GPCP	2.5°×2.5°	Monthly	1979-2020
	GPM	0.1°×0.1°	Monthly	2000-2020
	JRA55	0.5°×0.5°	Monthly	1959-2020
	MERRA2	0.5°×0.625°	Monthly	1980-2020
	MSWEP	0.5°×0.5°	Monthly	1979-2020
	TRMM	0.25°×0.25°	Monthly	1998-present
Evaporation	ERA5 Land	0.1°×0.1°	Monthly	1981-2020
	FLUXCOM	0.5°×0.5°	Monthly	2001-2015
	GLDAS22 CLSM	0.25°×0.25°	Daily	2003-2020
	GLDAS20 CLSM/NOAH/VIC	1.0°×1.0°	Monthly	1979-2014
	GLDAS21 NOAH/CLSM/VIC	1.0°×1.0°	Monthly	2000-2020
	GLEAM	0.25°×0.25°	Monthly	1980-2018
	JRA55	0.5°×0.5°	Monthly	1959-2020
	MERRA2	0.5°×0.625°	Monthly	1980-2020
	MOD16	0.5°×0.5°	Monthly	2000-2014
	SEBBop	0.5°×0.5°	Monthly	2003-2020
Runoff	ERA5 Land	0.1°×0.1°	Monthly	1981-2020
	GLDAS22 CLSM	0.25°×0.25°	Daily	2003-2020
	GLDAS20 CLSM/NOAH/VIC	1.0°×1.0°	Monthly	1979-2014
	GLDAS21 CLSM/NOAH/VIC	1.0°×1.0°	Monthly	2000-2020
	GRUN	0.5°×0.5°	Monthly	1902-2014
	JRA55	0.5°×0.5°	Monthly	1959-2020
	MERRA5	0.5°×0.625°	Monthly	1980-2020
Terrestrial water storage	GRACE JPL mascons	0.5°×0.5°	Monthly	2002-present
	GRACE CSR mascons	0.5°×0.5°	Monthly	2002-present

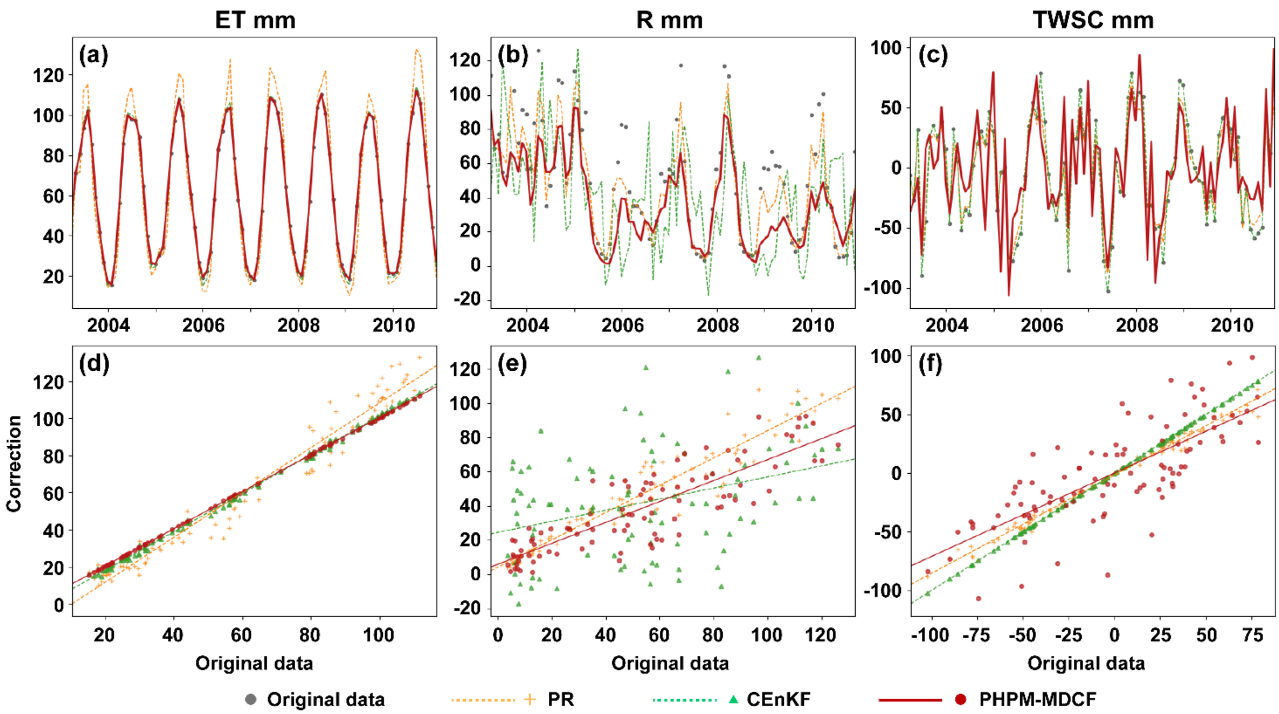


Figure S11. Same as Fig. 11, but for basin 1557500.

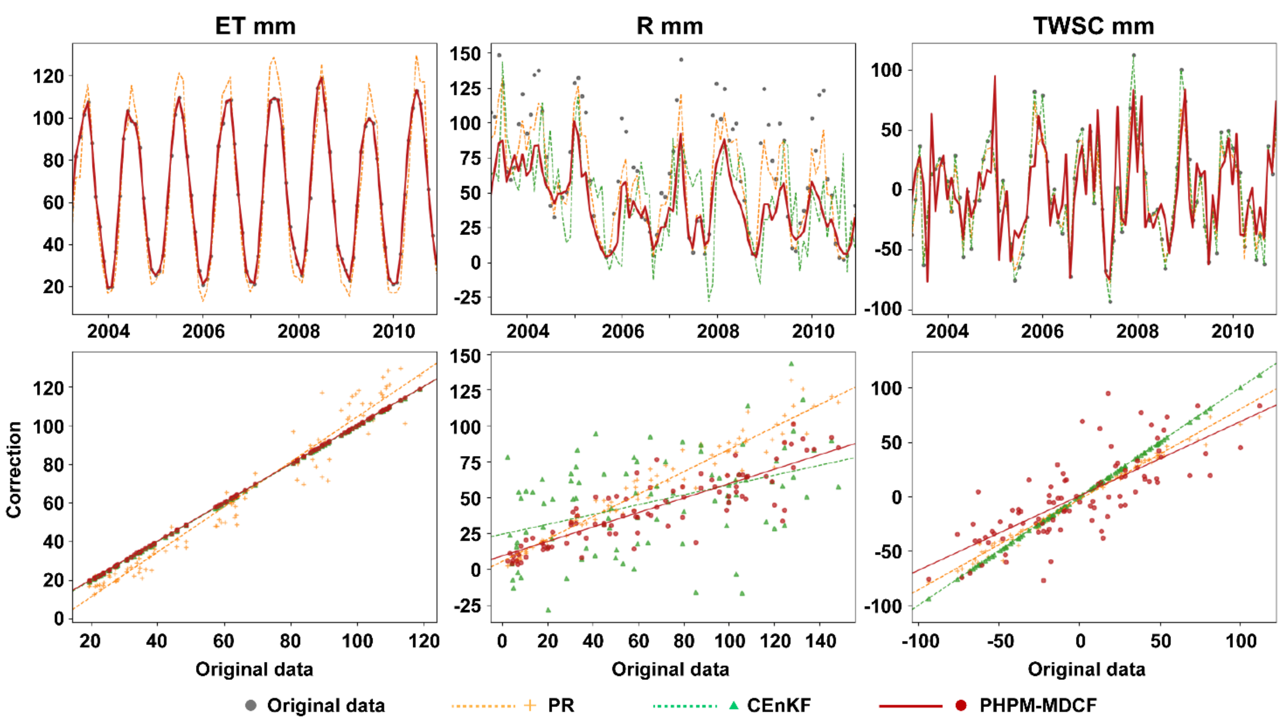


Figure S12. Same as Fig. 11, but for basin 3070500.

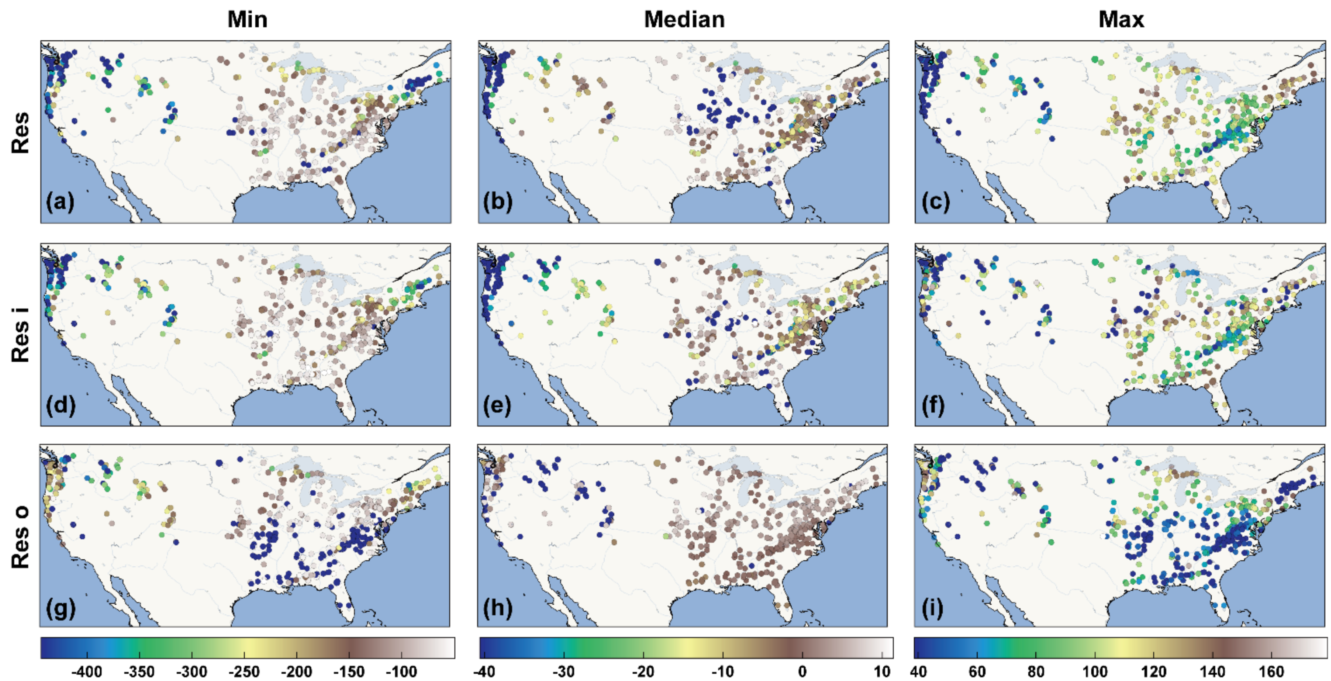


Figure S13. Same as Fig. 4, but for residuals decomposition excluding SWE.

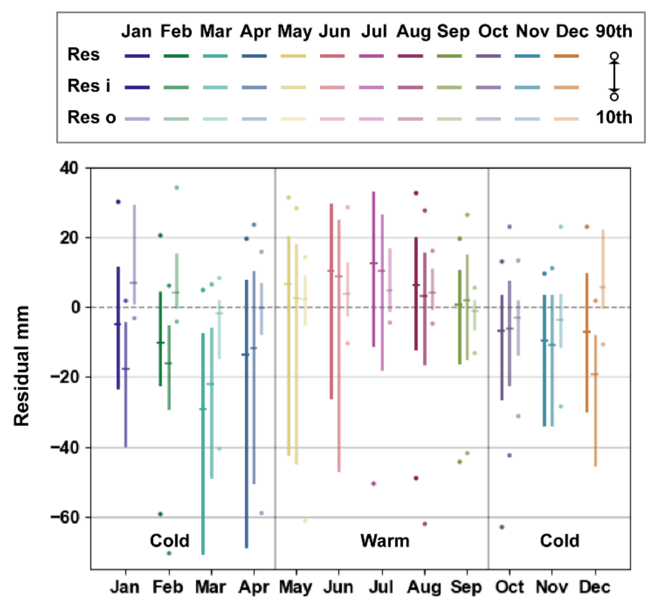


Figure S14. Same as Fig. 5, but for residuals decomposition excluding SWE.

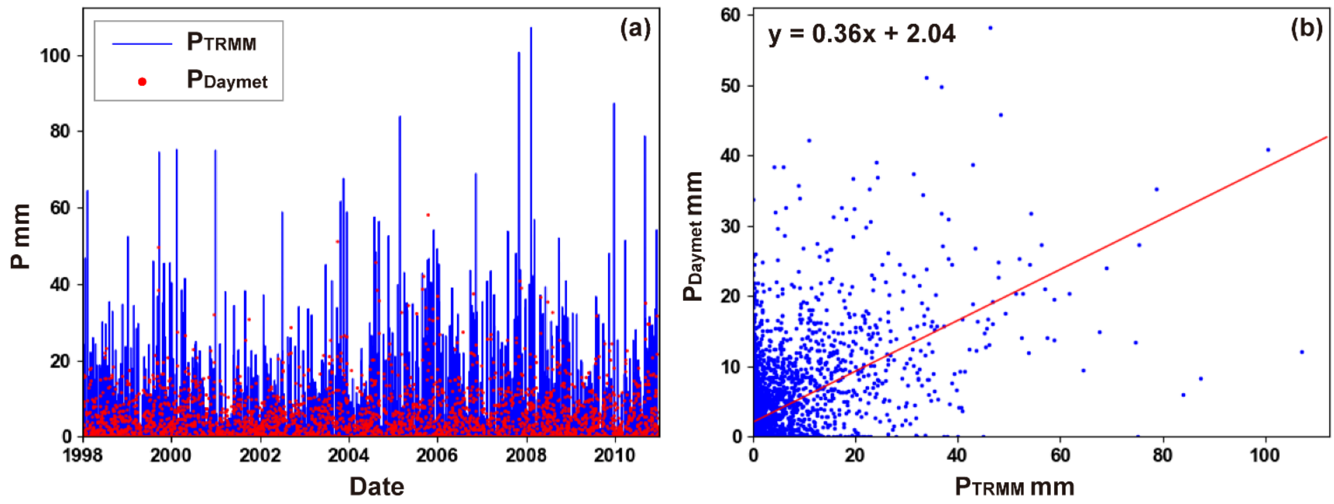
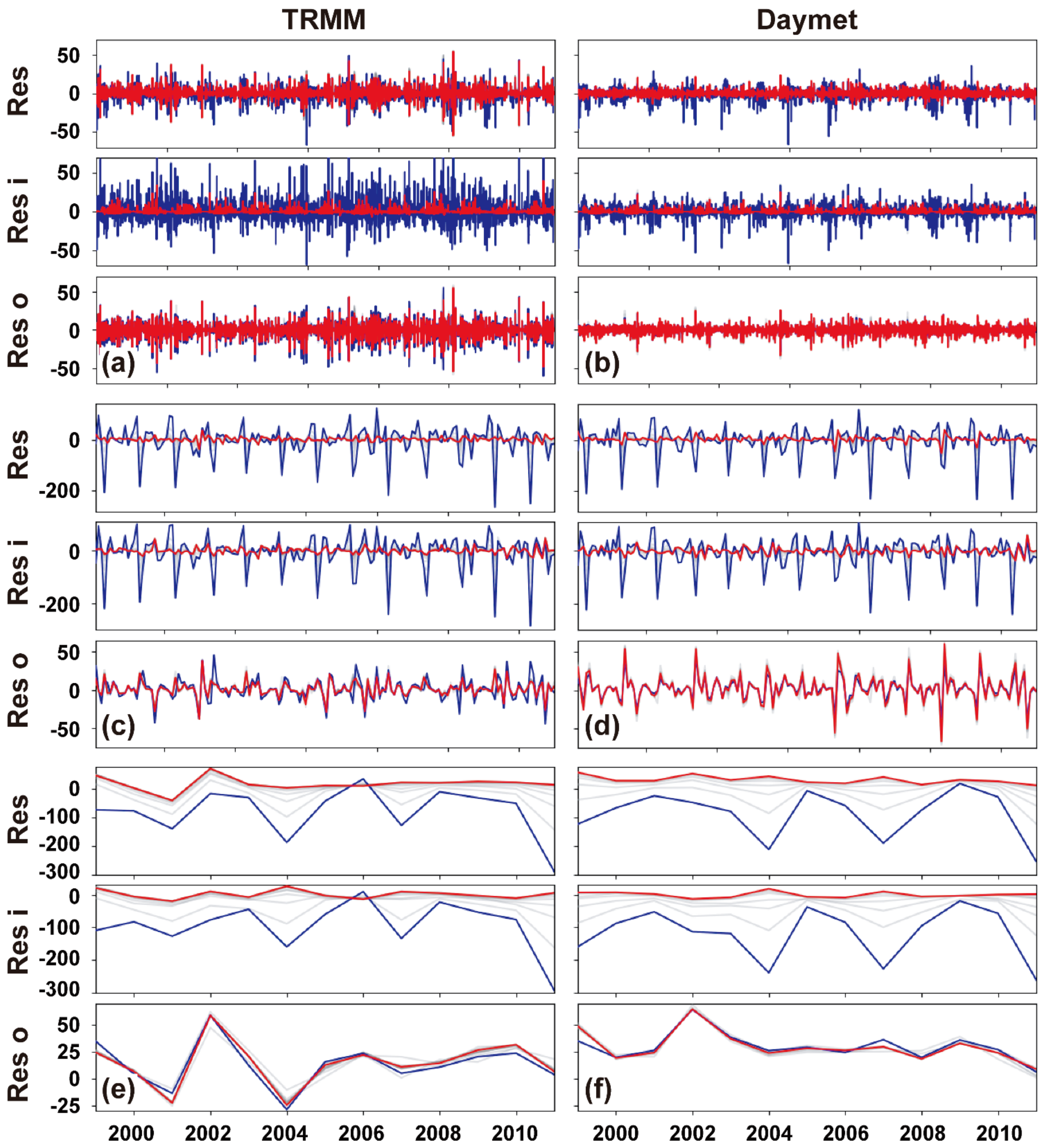


Figure S15. Comparison of TRMM and Daymet precipitation products.



50 **Figure S16.** Comparison of correction results based on different forcing datasets (TRMM and Daymet) at basin 1013500. (a-b) Time series of three types of residuals at daily, (c-d) monthly, (e-f) and yearly timescales, respectively.

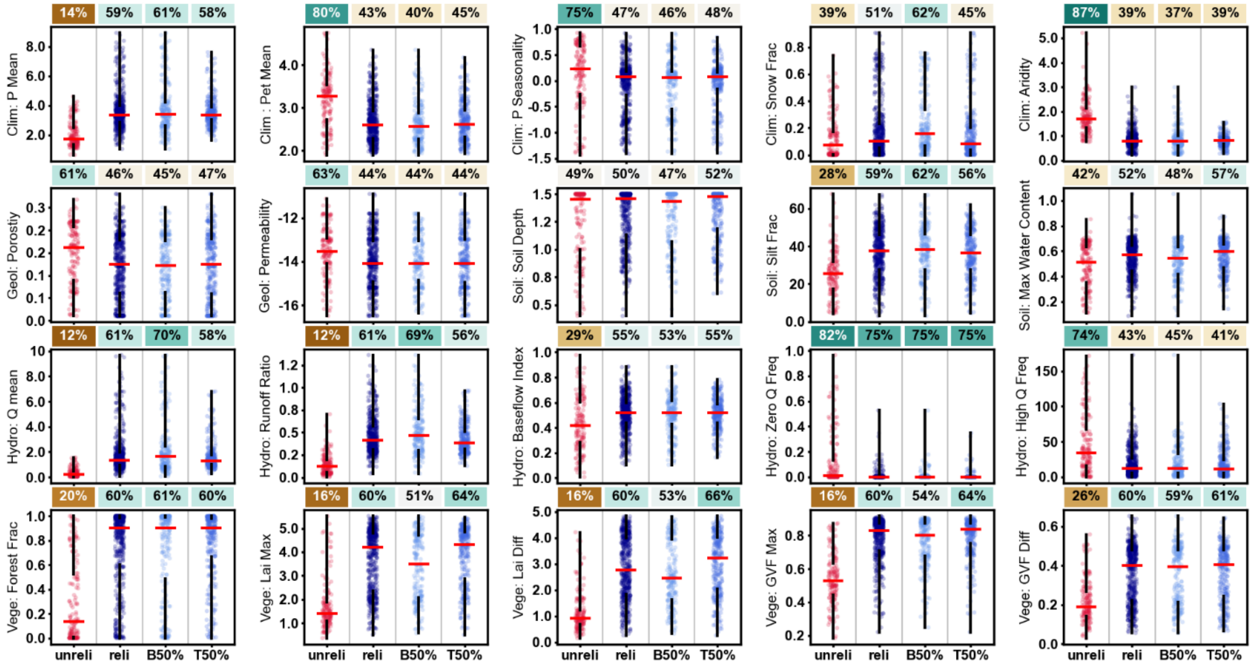


Figure S17. Grouping of basin characteristics based on model performance in runoff. Four groups labelled as “unreli”, “reli”, “B50%”, and “T50%” represent basin groupings characterized by unreliable simulations, reliable simulations, below-average model performance, and above-average model performance, respectively. The cumulative probability of the median value for each group is labelled at the top of each panel.

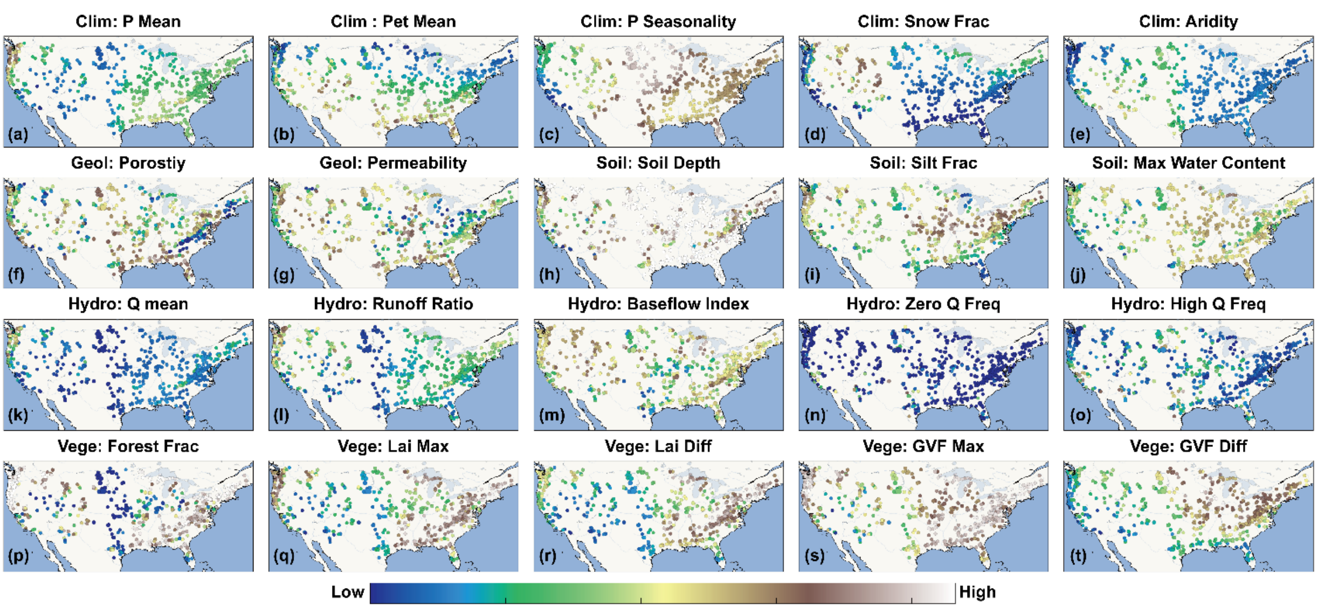


Figure S18. Spatial patterns of selected basin characteristics.