

Supplement to: A 204-year tree-ring reconstruction of dry-season precipitation for the Lugu Lake basin, southeastern Tibetan Plateau

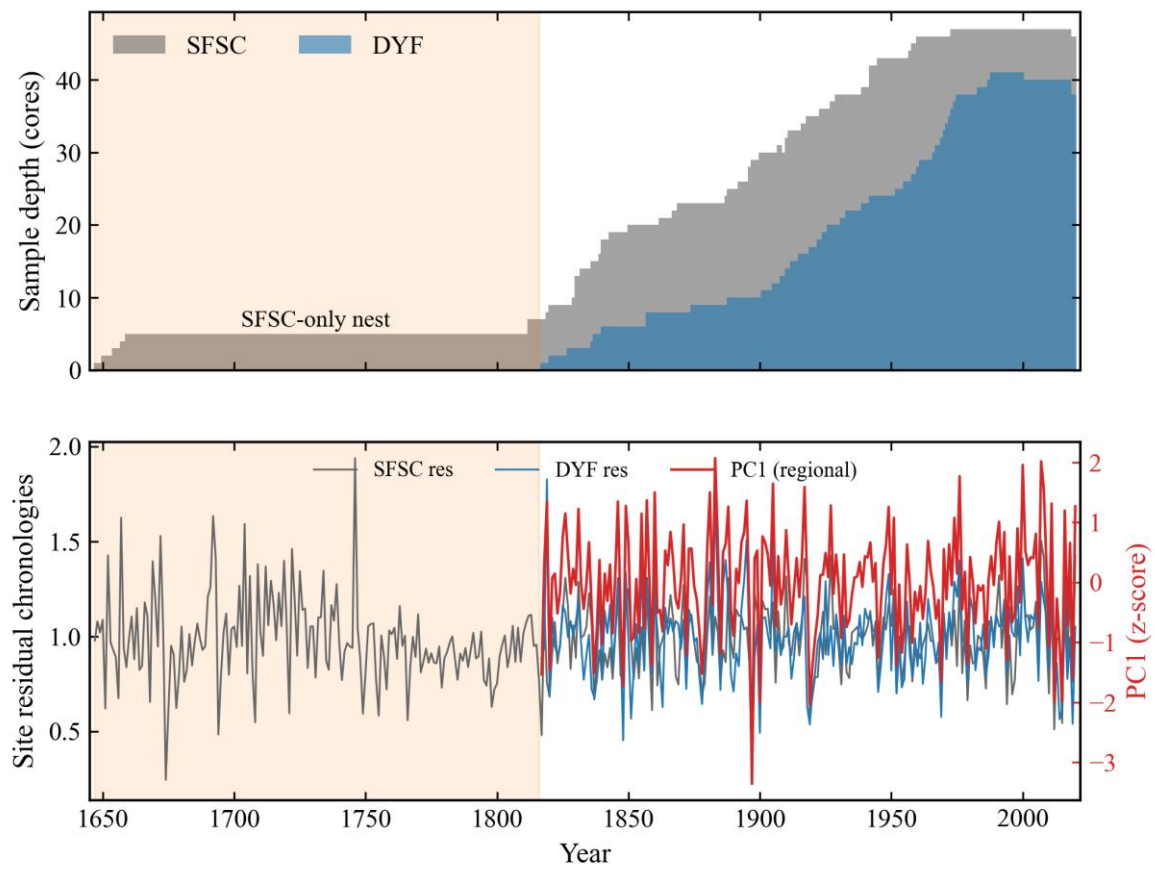


Fig. S1. Raw SFSC and DYF standardised/ARSTAN chronologies and annual growth indices with replication.

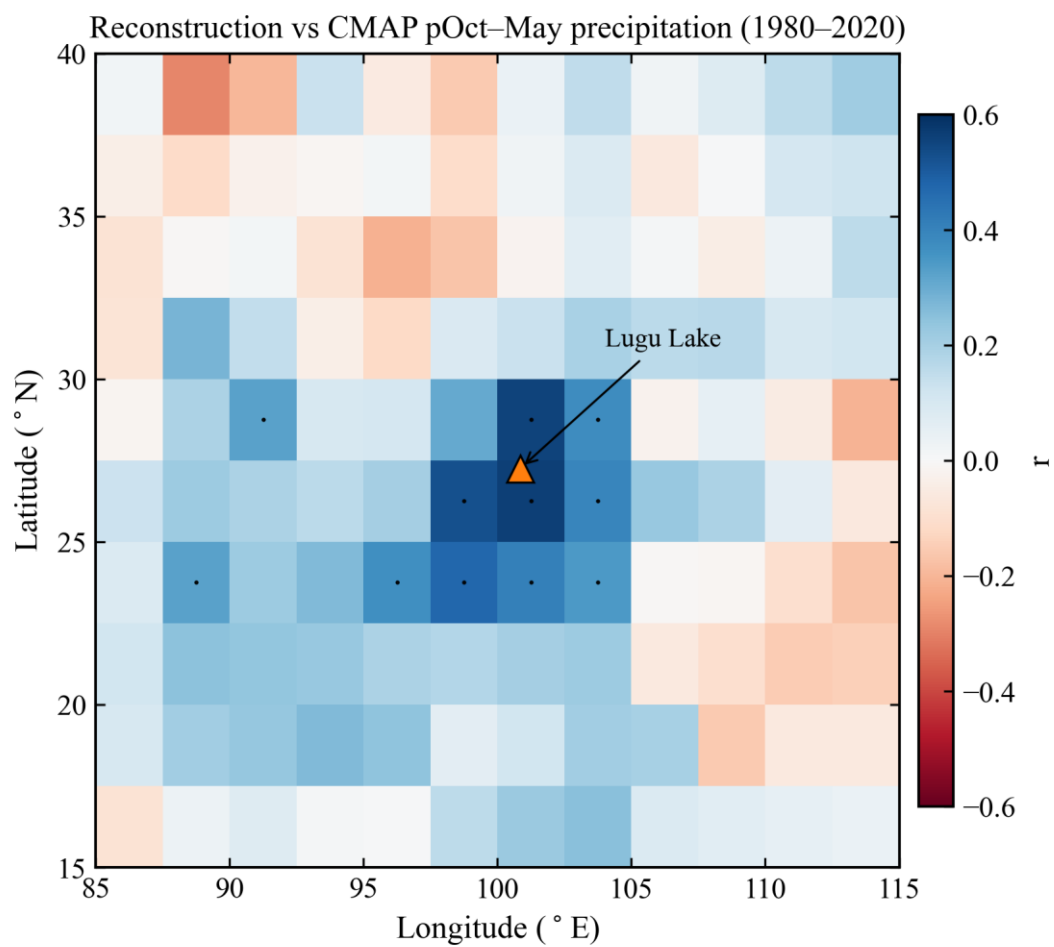


Fig. S2. Satellite-era (CMAP, 1979–2019) grid-point correlation of the reconstruction with seasonal precipitation.

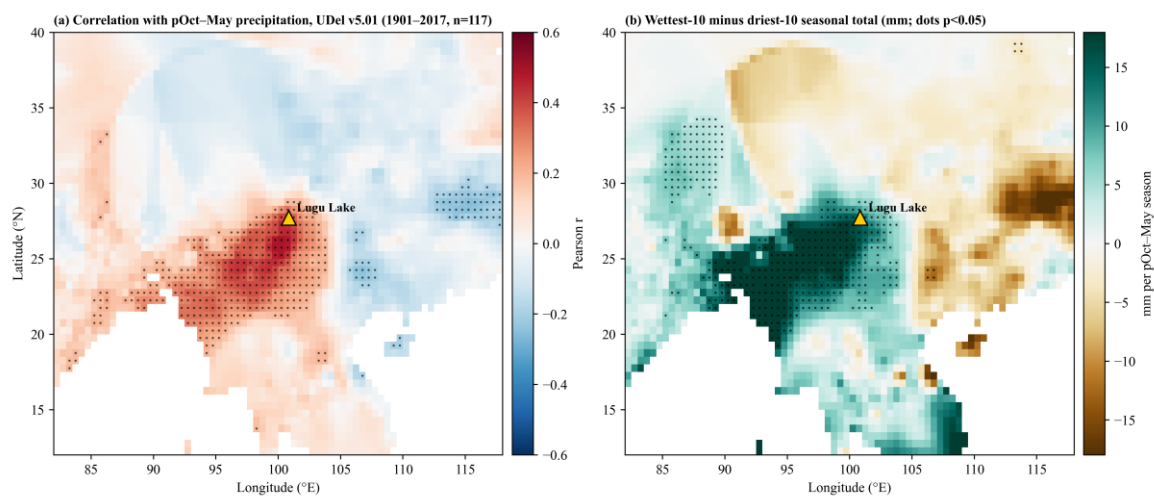


Fig. S3. UDelaware v5.01 long-record (1901–2017, n = 117) validation: (a) grid-point correlation with pOct–cMay precipitation; (b) wettest-10 minus driest-10 composite (mm; dots $P < 0.05$).

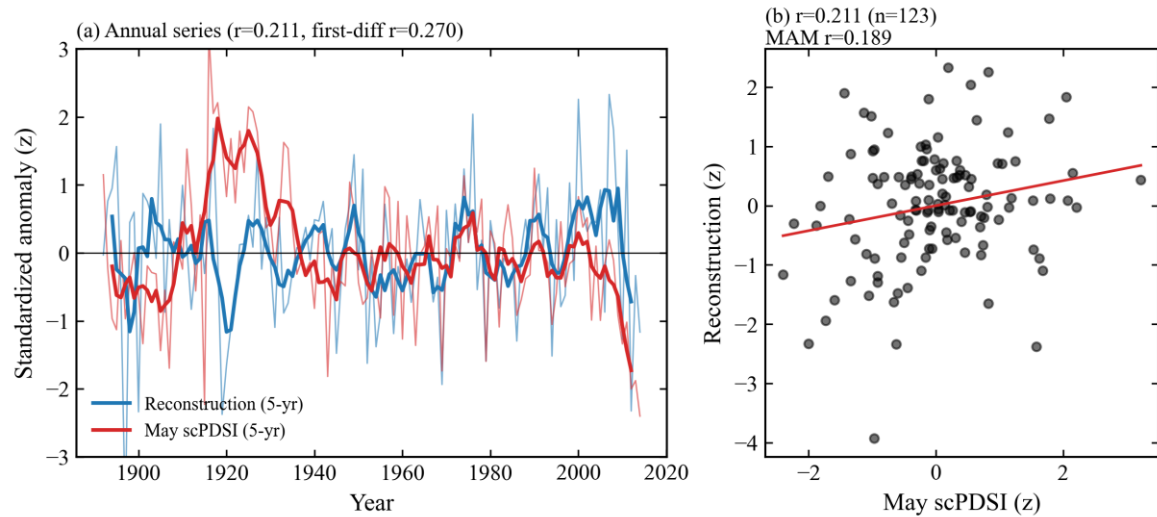


Fig. S4. PDSI-based diagnostic comparison field.

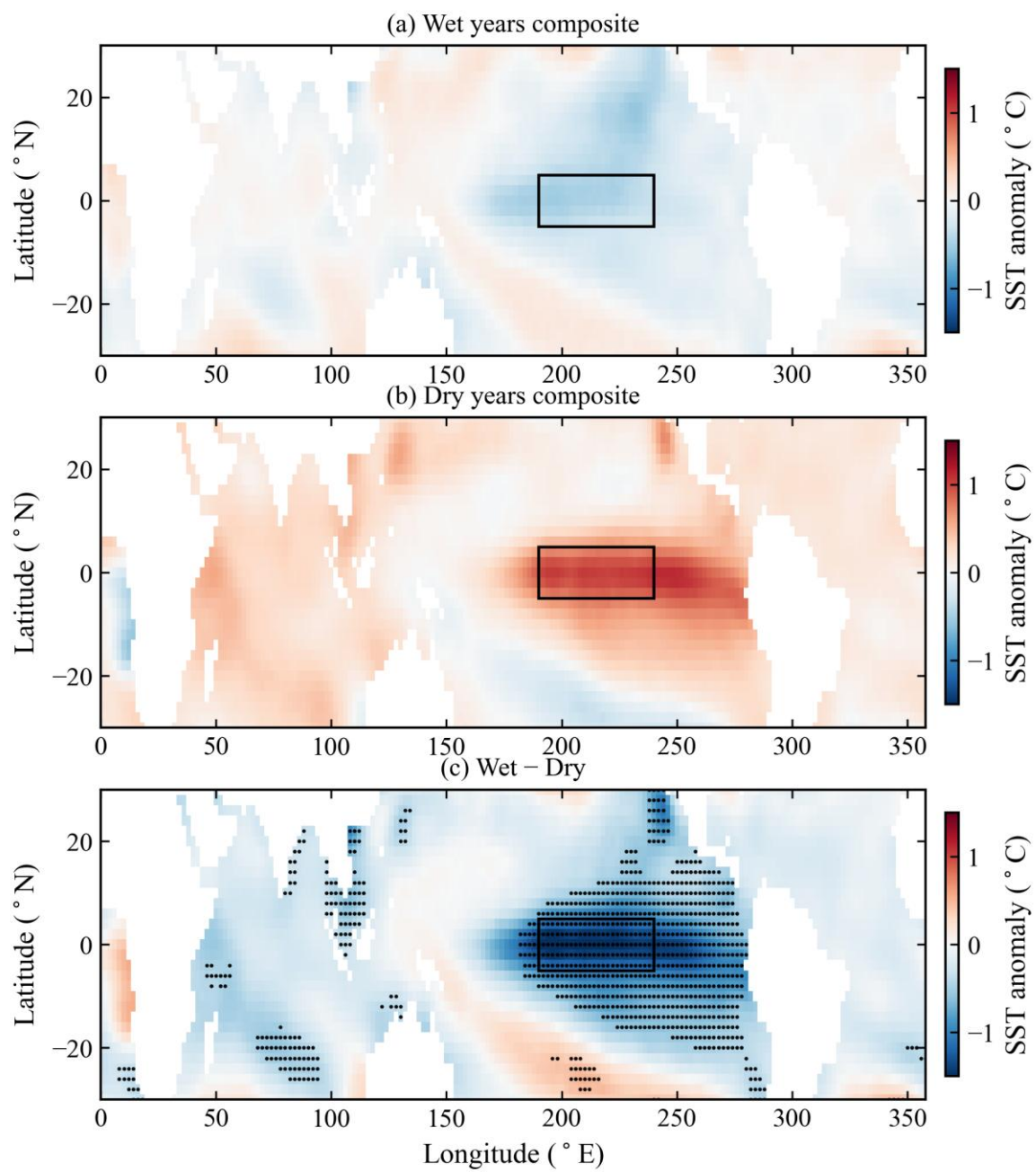


Fig. S5. ERSSTv5 wet-minus-dry SST composite.

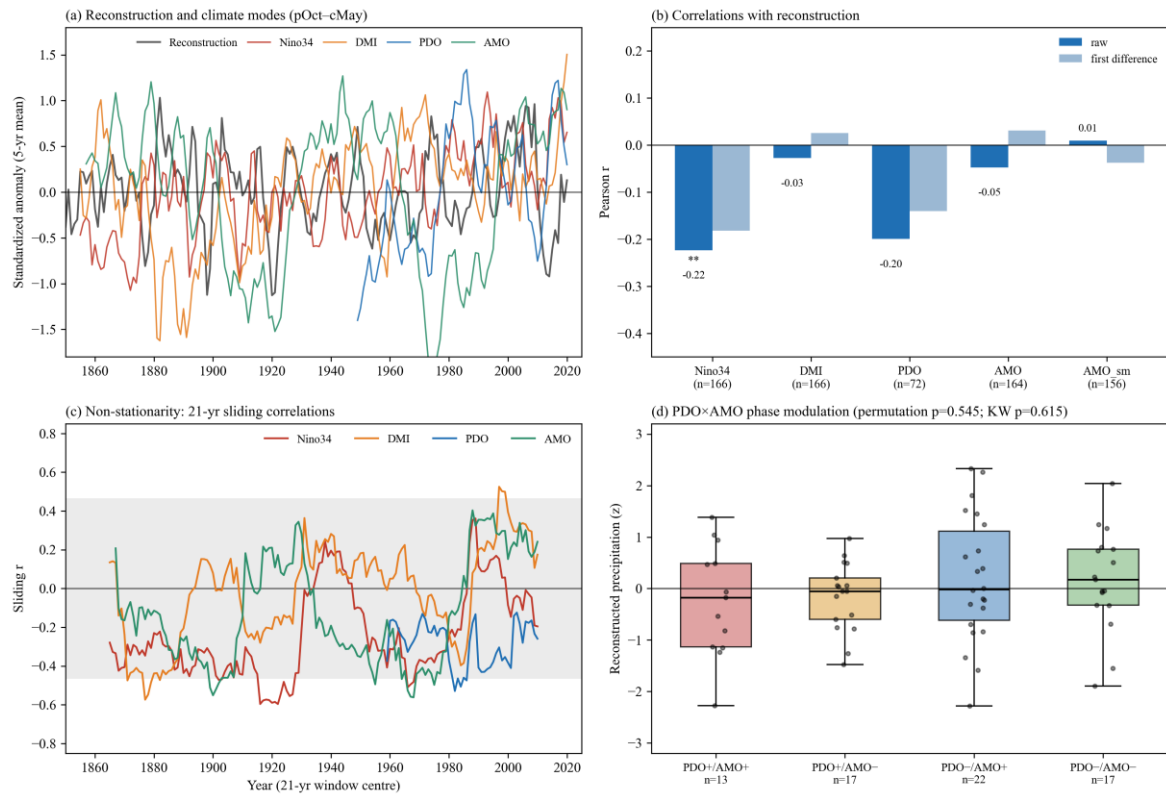


Fig. S6. Niño3.4/PDO/AMO/IOD correlations with the reconstruction and the PDO × AMO four-phase analysis.

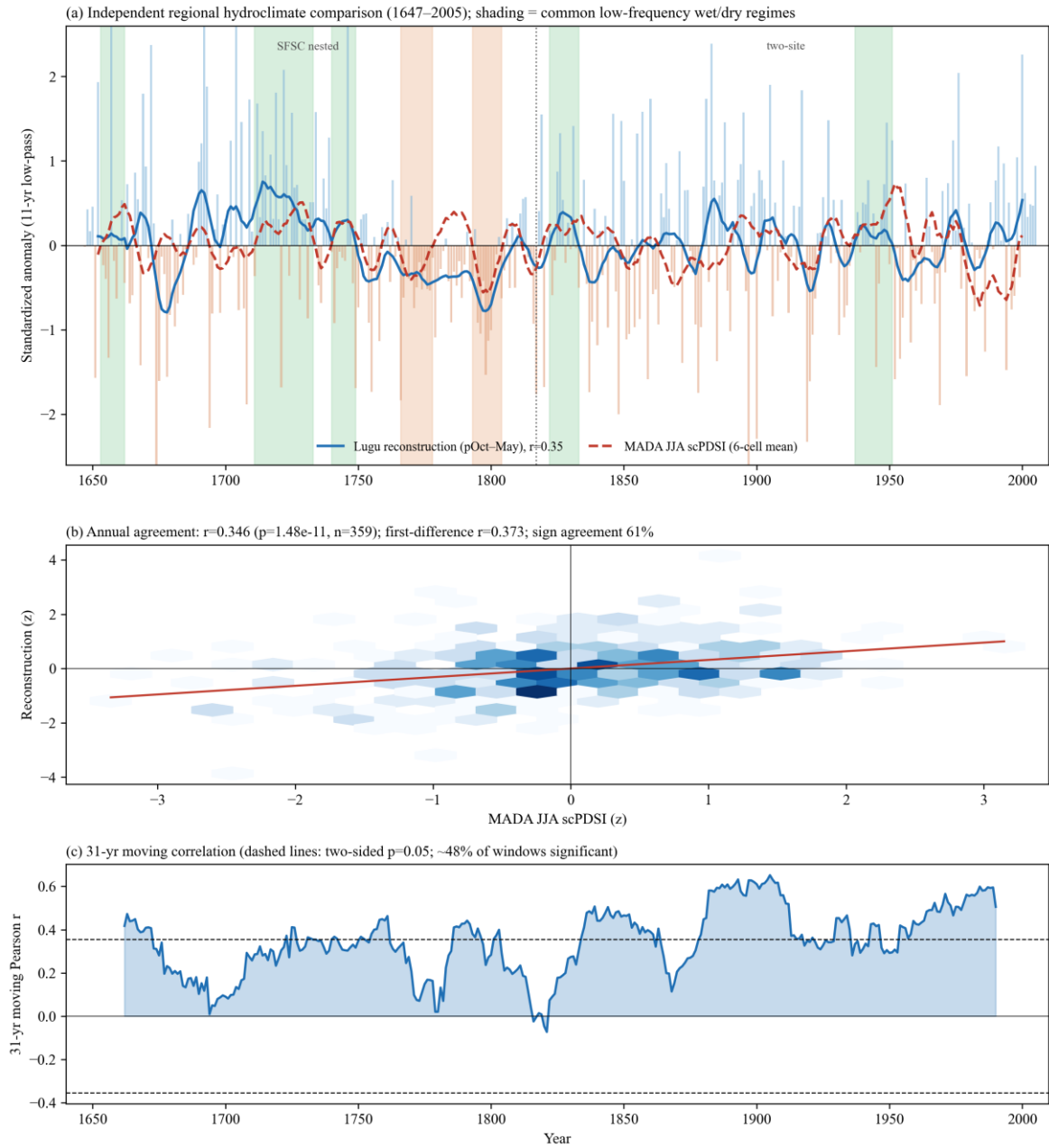


Fig. S7. Regional comparison with MADA scPDSI (time series, scatter, co-extreme sign agreement 91%, common low-frequency regimes; $r = 0.390$).

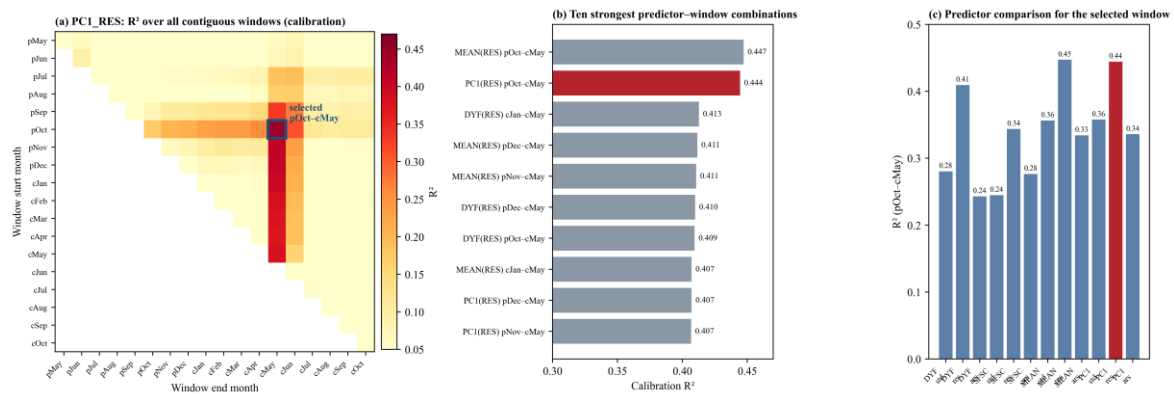


Fig. S8. Seasonal-window optimisation: 18×18 start $\times$ end-month R^2 matrix, top-10 predictor-window ranking, and predictor-variant comparison.

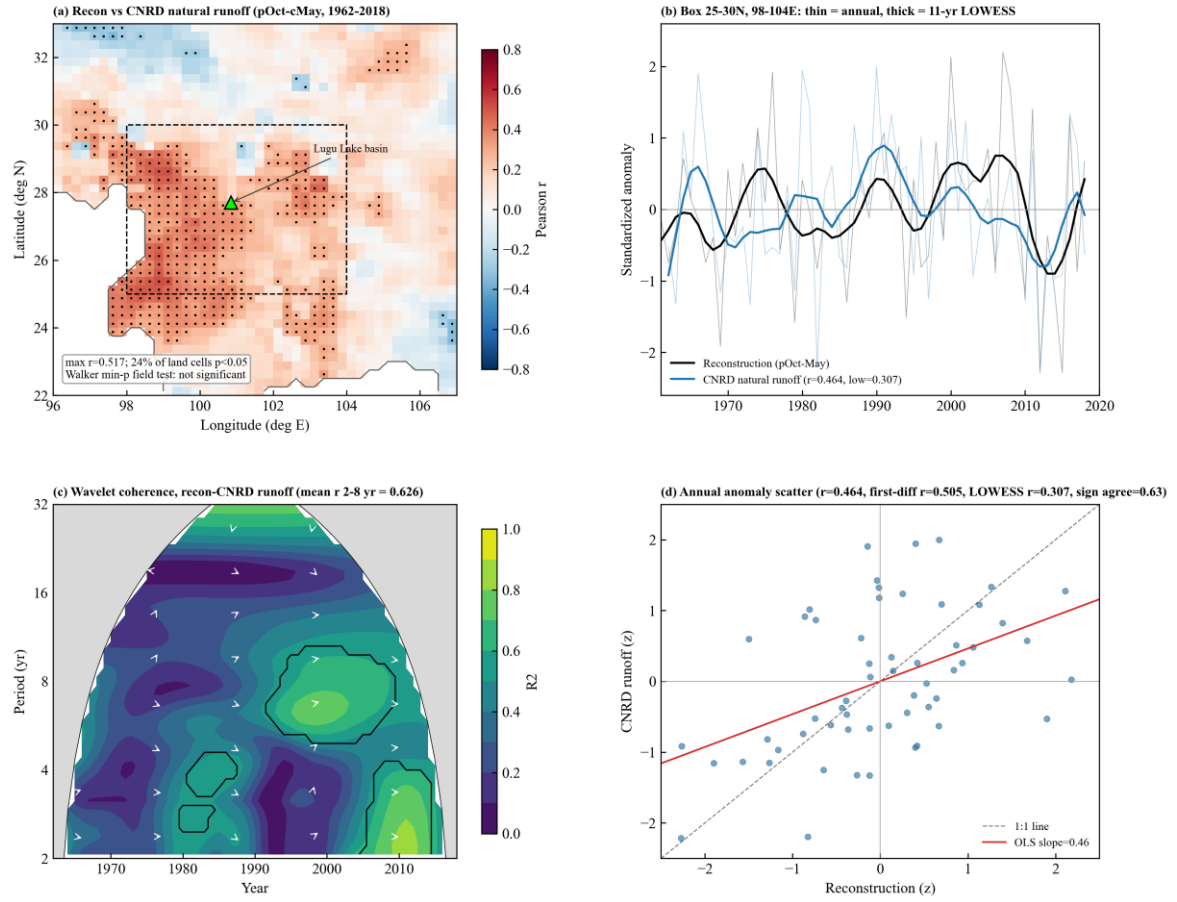


Fig. S9. Hydrological-consistency diagnostics without local gauge data, using CNRD v1.0 gridded natural runoff (the local analogue of the runoff comparison in Hou et al., 2026). (a) Grid-point Pearson correlation of the reconstruction with CNRD pOct-cMay natural runoff over the 57 complete water years 1962–2018 (dots: $P < 0.05$; grey line: valid-CNRD land-mask boundary; dashed box: 25–30°N, 98–104°E regional series area; green triangle: Lugu Lake); 24.3% of 1,674 land cells are nominally significant ($\approx 5\times$ the 5% expectation; maximum $r = 0.517$), although the field narrowly misses the Walker minimum-P threshold and the positive centre lies west-southwest of the lake. (b) Standardised annual (thin) and 11-yr LOWESS (thick) reconstruction (black) and CNRD box natural runoff (blue). (c) Squared wavelet coherence between the reconstruction and the CNRD box runoff (1962–2018; contours: 95% against 300 bivariate AR(1) surrogates; hatching: outside the cone of influence; arrows: phase); coherence is strongest at 2–8 yr (mean $r = 0.626$), concentrated in 1995–2010. (d) Standardised annual scatter of reconstruction versus CNRD box runoff (dashed: 1:1 line; red: OLS fit, slope 0.46), illustrating the calibration-versus-comparison attenuation discussed in Section 4.5.

Supplementary tables

Table S1a. Annual logistic regression of extreme occurrence $I(|z| \geq 1.5)$ on calendar year.

Period	Extreme	n	Events	Slope /dec	OR /dec	LRT	P_LRT	Wald z	P_Wald	CI lo	CI hi
1817-2020	any	204	29	-0.016	0.984	0.232	0.630	-0.483	0.629	-0.094	0.072
1817-2020	wet	204	13	-0.021	0.980	0.178	0.673	-0.423	0.672	-0.150	0.116
1817-2020	dry	204	16	-0.011	0.989	0.059	0.808	-0.243	0.808	-0.113	0.103
1647-2020	any	374	54	-0.016	0.984	1.310	0.252	-1.149	0.251	-0.054	0.013
1647-2020	wet	374	27	-0.029	0.971	2.465	0.116	-1.605	0.108	-0.080	0.010
1647-2020	dry	374	27	0.000	1.000	0.000	0.992	0.010	0.992	-0.047	0.040

Intercepts are centred at the mean year of each period (1918 for 1817–2020; 1834 for 1647–2020). OR per decade = $\exp(\text{slope} \times 10)$; LRT compares against the intercept-only (constant-probability) model; CI from 5,000 moving-block bootstrap resamples (block = 5 yr).

Table S1b. Extreme counts in non-overlapping 20-yr blocks (1817–2020).

block	start	years	wet	dry	any	any rate per30	wet rate per30	dry rate per30
1817-1836	1817	20	1	2	3	4.500	1.500	3.000
1837-1856	1837	20	1	2	3	4.500	1.500	3.000
1857-1876	1857	20	2	1	3	4.500	3.000	1.500
1877-1896	1877	20	3	1	4	6.000	4.500	1.500
1897-1916	1897	20	1	2	3	4.500	1.500	3.000
1917-1936	1917	20	1	2	3	4.500	1.500	3.000
1937-1956	1937	20	0	1	1	1.500	0.000	1.500
1957-1976	1957	20	1	1	2	3.000	1.500	1.500
1977-1996	1977	20	0	1	1	1.500	0.000	1.500
1997-2016	1997	20	3	2	5	7.500	4.500	3.000
2017-2020	2017	4	0	1	1	7.500	0.000	7.500

The partial 2017–2020 block (2 extremes in 4 yr) is descriptive only and excluded from rate comparisons.

Table S1c. Extreme counts in non-overlapping 30-yr blocks anchored at 1817.

block	start	years	wet	dry	any	any rate per30	wet rate per30	dry rate per30
1817-1846	1817	30	2	3	5	5.000	2.000	3.000
1847-1876	1847	30	2	2	4	4.000	2.000	2.000
1877-1906	1877	30	4	3	7	7.000	4.000	3.000
1907-1936	1907	30	1	2	3	3.000	1.000	2.000
1937-1966	1937	30	0	1	1	1.000	0.000	1.000
1967-1996	1967	30	1	2	3	3.000	1.000	2.000
1997-2020	1997	24	3	3	6	7.500	3.750	3.750

The partial block 1997–2020 holds six extremes in 24 yr (7.5 per 30 yr; three wet, three dry). The latest-minus-earliest contrast (+1 per 30 yr) is not significant under 5-, 10-, or 15-yr moving-block bootstrap nulls ($P = 0.84, 0.91, 0.73$) or against spectral surrogates that preserve the full 1817–2020 power spectrum ($P = 0.63$).

Table S1d. Non-stationary GEV models for wet and dry tails (location linear in time).

tail	mu0	sigma	shape	mu1 per century	mu1 per decade	RL20 1817	RL20 2020	delta RL20	stationary LL	nonstat LL	LRT	p
wet	139.080	48.720	-0.346	3.160	0.320	229.500	235.900	6.400	-1072.670	-1072.48	0.372	0.542

										0		
dry	-172.98 0	44.14 0	-0.170	-3.070	-0.310	-70.000	-76.200	-6.200	-1072.680	-1072.52 0	0.32 6	0.56 8

ARL20 = change of the 20-yr return level from 1817 to 2020 (mm); LRT compares with stationary GEV.

Table S2. Per-model CMIP6 dry-season (pOct–cMay) statistics for the Lugu Lake box (25–30°N, 99–104°E), r1ilp1fl.

model	hist mean mm	baseline mean mm	mid mean mm	end mean mm	delt a mid pct	delt a end pct	delta end mm	baseline sd	end sd	sd change pct	end Q10 rate pct	end Q90 rate pct	r ens o hist	r ens o end
BCC-CSM2-MR	663.6 00	651.4 00	640.5 00	755.7 00	-1.70 0	16.0 00	104.3 00	112.4 00	158.8 00	41.2 00	10.0 00	35.0 00	-0.0 65	0.1 10
CanESM5	474.5 00	478.5 00	548.4 00	800.8 00	14.6 00	67.4 00	322.3 00	124.0 00	197.1 00	58.9 00	0.00 0	75.0 00	-0.1 86	0.2 62
MIROC6	709.7 00	693.6 00	772.1 00	874.0 00	11.3 00	26.0 00	180.4 00	120.2 00	199.1 00	65.7 00	0.00 0	50.0 00	0.3 12	0.1 57
IPSL-CM6A-LR	561.4 00	545.9 00	574.0 00	617.4 00	5.20 0	13.1 00	71.50 0	92.50 0	107.0 00	15.6 00	5.00 0	45.0 00	-0.1 37	-0.3 52

Changes vs the 1995–2014 baseline; tail frequencies are percentages of 2081–2100 years beyond baseline Q10/Q90. Absolute mm values are coarse-grid box means and are not directly comparable to the site reconstruction.

Table S2 (continued). Correlation of regional dry-season precipitation with NDJF Niño3.4.

model	period	r	n
BCC-CSM2-MR	historical 1950-2014	-0.065	65
BCC-CSM2-MR	ssp585 2081-2100	0.110	20
CanESM5	historical 1950-2014	-0.186	65
CanESM5	ssp585 2081-2100	0.262	20
MIROC6	historical 1950-2014	0.312	65
MIROC6	ssp585 2081-2100	0.157	20
IPSL-CM6A-LR	historical 1950-2014	-0.137	65
IPSL-CM6A-LR	ssp585 2081-2100	-0.352	20

Observed reconstruction: $r = -0.223$ (1855–2020, $P = 0.004$ with effective degrees of freedom). Future window $n = 20$ ($|r| > 0.44$ needed for nominal significance); per-model changes are not interpreted individually.

Table S3a. Sensitivity of extreme-event counts and logistic trend to the $|z|$ threshold.

threshold	n events 1817 2020	rate pct	gaussian rate pct	count 1991 2020	gaussian expect per30	slope per decade	p LRT
1.000	59.000	28.900	31.700	14.000	9.500	0.011	0.668
1.250	45.000	22.100	21.100	10.000	6.300	-0.002	0.933
1.500	29.000	14.200	13.400	6.000	4.000	-0.016	0.630
1.750	16.000	7.800	8.000	6.000	2.400	0.081	0.077
2.000	9.000	4.400	4.600	4.000	1.400	0.127	0.042

The logistic trend is absent at $|z| \geq 1.0$ ($P = 0.668$) and strengthens only at the highest thresholds ($P = 0.933$ at 1.25, 0.630 at 1.5, 0.077 at 1.75, 0.042 at $|z| \geq 2.0$).

Table S3b. Sensitivity of 30-yr block counts to the partition alignment (offset 0–29 yr from 1817).

offset	latest block	latest count	max count	latest is max	latest is unique max
0	1967-1996	3	7	False	False
1	1968-1997	3	7	False	False
2	1969-1998	3	6	False	False

3	1970-1999	2	6	False	False
4	1971-2000	3	6	False	False
5	1972-2001	3	5	False	False
6	1973-2002	3	5	False	False
7	1974-2003	3	6	False	False
8	1975-2004	3	6	False	False
9	1976-2005	3	6	False	False
10	1977-2006	2	6	False	False
11	1978-2007	3	5	False	False
12	1979-2008	4	5	False	False
13	1980-2009	3	6	False	False
14	1981-2010	3	7	False	False
15	1982-2011	3	7	False	False
16	1983-2012	4	7	False	False
17	1984-2013	4	7	False	False
18	1985-2014	4	7	False	False
19	1986-2015	5	6	False	False
20	1987-2016	5	6	False	False
21	1988-2017	5	5	True	False
22	1989-2018	5	5	True	False
23	1990-2019	6	6	True	True
24	1991-2020	6	6	True	False
25	1962-1991	3	6	False	False
26	1963-1992	3	6	False	False
27	1964-1993	3	6	False	False
28	1965-1994	3	6	False	False
29	1966-1995	3	7	False	False

The latest complete block is the maximum in only 4/30 alignments (13%) and the unique maximum for a single offset (offset 23, 1990–2019).

Table S3c. Significance of the latest-minus-earliest 30-yr extreme-count contrast (+1 per 30 yr) under serial-dependence-preserving nulls.

boot block yr	p	CI95 low per30	CI95 high per30
5	0.841	-6.000	7.000
10	0.905	-4.000	6.000
15	0.732	-4.000	6.000
spectral null	0.627	-5.000	5.000

Moving-block bootstrap with block lengths 5/10/15 yr (5,000 resamples) gives $P = 0.84, 0.91$ and 0.73 respectively; 5,000 random-phase spectral surrogates preserving the full 1817–2020 power spectrum give $P = 0.63$. The 15-yr block test has low power (few independent blocks per window).

Table S3d. Circularity check: extremes in 1991–2020 reconstructed with a transfer function calibrated on 1960–1990 only.

item	value
P1-only transfer fn (cal 1960-1990)	slope=63.03, intercept=160.5, r_cal=0.657
extremes 1991-2020 (P1-only)	6
extremes 1991-2020 (full cal)	6
common years	2000 2007 2008 2012 2015 2019

Six extremes in 1991–2020 (2000, 2007, 2008, 2012, 2015, 2019) are reproduced with a transfer function calibrated on 1960–1990 only, identical in timing to the full-period calibration, confirming the event timing is not a calibration artefact; this count (6) does not exceed the maximum earlier complete 30-yr block (7 in 1877–1906).

Table S4a. Red-noise test of persistent regimes (2,000 spectral surrogates of the 1817–2020 spectrum, smoothed and scanned with the same ≥ 10 -yr run rule).

stat	observed	null median	null p95	p value	null
n_regimes	14	11.000	14.000	0.082	spectral

					surrogates (random-phase FFT, 1817-2020 spectrum)
max_duration_yr	46	19.000	25.000	0.000	spectral surrogates (random-phase FFT, 1817-2020 spectrum)
n_amp_filtered	10	6.000	8.000	0.015	spectral surrogates (random-phase FFT, 1817-2020 spectrum)

The number of regimes is consistent with the null ($P = 0.08$); the maximum duration (46 yr, 1764–1809) exceeds the null 95th percentile (25 yr; $P < 0.001$).

Table S4b. Segment statistics of the reconstruction and median sample depth.

segment	note	n	mean mm	sd mm	cv pct	SFSC cores median	SFSC cores min	DYF cores median
1647-1816	SFSC single-tree nest	170	156.500	45.810	29.300	5	1	0
1817-2020	two-site period	204	157.300	46.700	29.700	35	7	16

The early SFSC-only segment rests on a median of five cores from a single tree before ~1800, whereas the two-site period is sampled by 35 cores (SFSC) and 16 cores (DYF); although its reconstructed standard deviation (45.8 mm) is not inflated relative to the two-site value (46.7 mm), its extreme counts depend on few cores, so z-scores are computed on the 1817–2020 basis and inference is restricted to that period.

Table S4c. Sample depth (cores / trees) per 50-yr window.

window	SFSC cores	SFSC trees	DYF cores	DYF trees
1650-1699	5	1	0	0
1700-1749	5	1	0	0
1750-1799	5	1	0	0
1800-1849	19	9	6	3
1850-1899	29	14	10	5
1900-1949	44	20	24	13
1950-1999	47	22	42	21
2000-2049	47	22	41	21

Before 1800 the SFSC chronology comprises five cores from a single tree, so early EPS values (0.947–0.985) reflect within-tree rather than stand-level signal strength.

Table S5a. Key correlations with nominal and effective-degree-of-freedom P values (Bretherton et al., 1999).

target	period	n	r	p nominal	ar1 x	ar1 y	n eff	p effective
Nino3.4 (dry season)	1855-2020	166	-0.223	0.004	-0.070	0.097	168.300	0.004
MADA JJA scPDSI (full overlap)	1647-2005	359	0.346	0.000	0.016	-0.055	359.600	0.000
MADA JJA scPDSI (two-site period)	1817-2005	189	0.390	0.000	-0.037	-0.106	187.500	0.000
UDel pOct-May	1901-2017	117	0.228		-0.019	0.100	117.400	0.013

precip (box median, 25-30N 99-104E)								
UDel pOct-May precip (box max, 25-30N 99-104E)	1901-2017	117	0.499		-0.019	0.100	117.400	0.000

The reconstruction is close to white noise (lag-1 autocorrelation ≈ -0.07), so effective- n P values are essentially unchanged from nominal values.

Table S5b. Walker field-significance test for the UDel grid-point correlation field (3,140 cells, 1901–2017).

test	value
N cells	3140
frac $p < 0.05$	0.1344
Walker alpha	1.63e-05
min p	0.00e+00
field significant	True

13.4% of cells are nominally significant (5% expected), and the minimum cell P value passes the Walker threshold (1.6×10^{-3}), so the field is field-significant.

Table S6. Wet/dry composite years and post-1900 sensitivity of the 700-hPa moisture-flux and Z500 composites.

group	mfc mean1e7	mfc mm day	u700 anom	v700 anom	z500 anom
wet	0.014	0.246	-0.175	-0.031	-4.210
dry	-0.062	-1.084	0.284	0.126	2.580

Composite years are the ten wettest and ten driest reconstructed dry seasons within the 20CRv3 overlap (1837–2015): wet 1883, 2007, 2000, 1976, 1905, 1917, 2008, 1881, 1860, 1857; dry 1897, 1919, 1900, 2012, 2015, 1969, 2019, 1878, 1920, 1859. MFC as column-equivalent convergence (mm day^{-1} ; 600–800-hPa layer scaling). The wet–dry asymmetry (near-zero wet mean, strong dry deficit) is unchanged or stronger when sparsely observed 19th-century years are excluded (wet–dry $P < 0.0001$).

Table S7. Instrumental-period hydrological consistency: reconstruction vs CNRD v1.0 natural runoff and independent land-moisture box series (pOct–cMay; land-masked, cosine-weighted).

Series	Period	n	r	P (eff.)	r_FD	r_LOW11	Sign agree	Co-extremes
CNRD v1.0 natural runoff, box	1962-2018	57	0.464	<0.001	0.505	0.307	0.630	1
CPC soil moisture, box	1961-2020	60	0.383	0.001	0.384	0.343	0.700	2
NCEP soil moisture 0-10 cm, box	1961-2020	60	0.396	0.002	0.477	0.131	0.520	3
NCEP soil moisture 10-200 cm, box	1961-2020	60	0.327	0.010	0.393	0.061	0.520	1
self-calibrated PDSI, box	1961-2014	54	0.410	0.001	0.514	0.292	0.560	1

P (eff.) uses Bretherton effective degrees of freedom from lag-1 autocorrelation of both series; sign agree is the fraction of same-sign annual anomalies; co-extremes counts years with $|z| \geq 1.5$ in both records. CNRD natural runoff (VIC-based naturalized runoff, the local analogue of

Hou et al., 2026) is available only for the 57 complete water years 1962–2018. CPC/NCEP soil moisture begin in 1948; the self-calibrated PDSI box is continuous 1892–2014. All are model/analysis products, not gauged discharge (see Sections 2.8 and 4.5).

Table S8. Long comparisons with independent tree-ring reconstructions and with pre-calibration scPDSI.

Series	Period	n	r	P (eff.)	r_FD	P_FD	r_LOW11	P_LOW11	Sign agree
PDSI box, pre-calibration	1892-1960	69	-0.025	0.841	-0.071	0.565	-0.110	0.368	0.550
Keyimu NW Yunnan Nov-Feb	1647-1959	313	0.224	<0.001	0.255	<0.001	0.138	0.014	0.570
Keyimu NW Yunnan Nov-Feb, instrumental	1960-2005	46	0.443	0.001	0.524	<0.001	0.604	<0.001	0.630
Liang central Yunnan winter-spring (published c1)	1817-1959	143	0.193	0.020	0.250	0.003	0.075	0.375	0.560
Liang central Yunnan winter-spring (published c1), instrumental	1960-2020	61	0.434	<0.001	0.486	<0.001	0.412	0.001	0.590
Liang central Yunnan (raw damped estimates c2)	1817-1959	143	0.047	0.569	0.056	0.505	0.012	0.884	0.530
Liang central Yunnan (raw damped estimates c2), instrumental	1960-2020	61	0.227	0.034	0.060	0.651	0.431	<0.001	0.570

Keyimu et al. (2021) = non-growing-season (Nov–Feb) precipitation, SE Tibetan Plateau; Liang et al. (2025) c1 = published previous-December–May reconstruction (primary), c2 = raw variance-damped regression estimates (sensitivity). Pre-calibration agreement is significant for Keyimu (annual) and for the Liang published series in first differences ($r = 0.253$, $P = 0.002$).

Table S9. Walker field-significance tests for the grid-point correlation fields (reconstruction vs CNRD natural runoff, 1962–2018, and independent land-moisture products, 1961–2020).

Dataset	N cells	n P<0.05	Frac sig.	min P	Walker α	Field sig.	max r
CNRD v1.0 natural runoff (0.25 deg, 1961-2018)	1674	407	0.243	3.80e-05	0.000	False	0.517
CPC soil moisture (0.5°)	484	70	0.145	1.29e-04	0.000	False	0.474

NCEP soil moisture 0-10 cm	30	10	0.333	9.84e-04	0.002	True	0.415
NCEP soil moisture 10-200 cm	30	6	0.200	0.006	0.002	False	0.349
self-calibrated PDSI (2.5°)	20	7	0.350	4.70e-05	0.003	True	0.524

Walker $\alpha = 1 - (1 - 0.05)^{(1/N)}$; the strict minimum- P test passes for the NCEP 0–10 cm and scPDSI fields. The finer CNRD 0.25° field has $\approx 5\times$ the chance-expected fraction of significant cells (24.3%; max $r = 0.517$, positive centre west–southwest of the lake) but its minimum P narrowly misses the conservative threshold (3.8×10^{-5} vs 3.1×10^{-5}), as does the CPC field (1.3×10^{-4} vs 1.1×10^{-4}); the scPDSI field ends in 2014 ($n = 54$).

Table S10. Expression of the 1764–1809 dry regime in the independent Keyimu et al. (2021) Nov–Feb reconstruction (1600–2005).

window	n	mean z	frac dry years	percentile vs pre1900
1764-1809 (Lugu 46-yr drought)	46	-0.040	0.480	0.515
1760s	10	-0.340	0.700	0.369
1770s	10	-0.180	0.700	0.458
1780s	10	-0.030	0.300	0.535
1790s	10	-0.200	0.500	0.442
1800s	10	0.470	0.200	0.721

z is computed within the Keyimu record; percentile is the empirical pre-1900 CDF below the window mean. The 46-yr regime is not corroborated ($z = -0.04$, 52nd percentile; only the 1760s–1770s are weakly dry, the 1800s wet).

Table S11. Band summary of squared wavelet coherence between the reconstruction and the CNRD natural-runoff box (1962–2018) and the CPC soil-moisture box (1948–2020).

pair	band	n cells	mean r	frac sig
reconstruction vs CNRD natural runoff	2-8 yr	1004	0.626	0.229
reconstruction vs CNRD natural runoff	8-20 yr	499	0.556	0.096
reconstruction vs CNRD natural runoff	20-50 yr	175	0.682	0.000
reconstruction vs CPC soil moisture	2-8 yr	1304	0.543	0.122
reconstruction vs CPC soil moisture	8-20 yr	694	0.545	0.022
reconstruction vs CPC soil moisture	20-50 yr	360	0.473	0.000

n_cells = time-scale cells inside the cone of influence; mean $r = \sqrt{(\text{mean } R^2)}$; frac sig. = fraction above the 95th percentile of 300 bivariate AR(1) surrogates. CNRD coherence is strongest at 2–8 yr (mean $r = 0.626$; 23% cells significant, 1995–2010); the high 20–50-yr mean coherence contains no significant cells and is not phase-locked. CPC coherence is moderate with scattered significant cells.