Supplement of Hydrol. Earth Syst. Sci., 28, 2139–2166, 2024
https://doi.org/10.5194/hess-28-2139-2024-supplement

Hydrology and Earth System Sciences
Open Access

Supplement of

Assessing downscaling methods to simulate hydrologically relevant weather scenarios from a global atmospheric reanalysis: case study of the upper Rhône River (1902–2009)

Caroline Legrand et al.

Correspondence to: Caroline Legrand (caroline.legrand@univ-grenoble-alpes.fr)

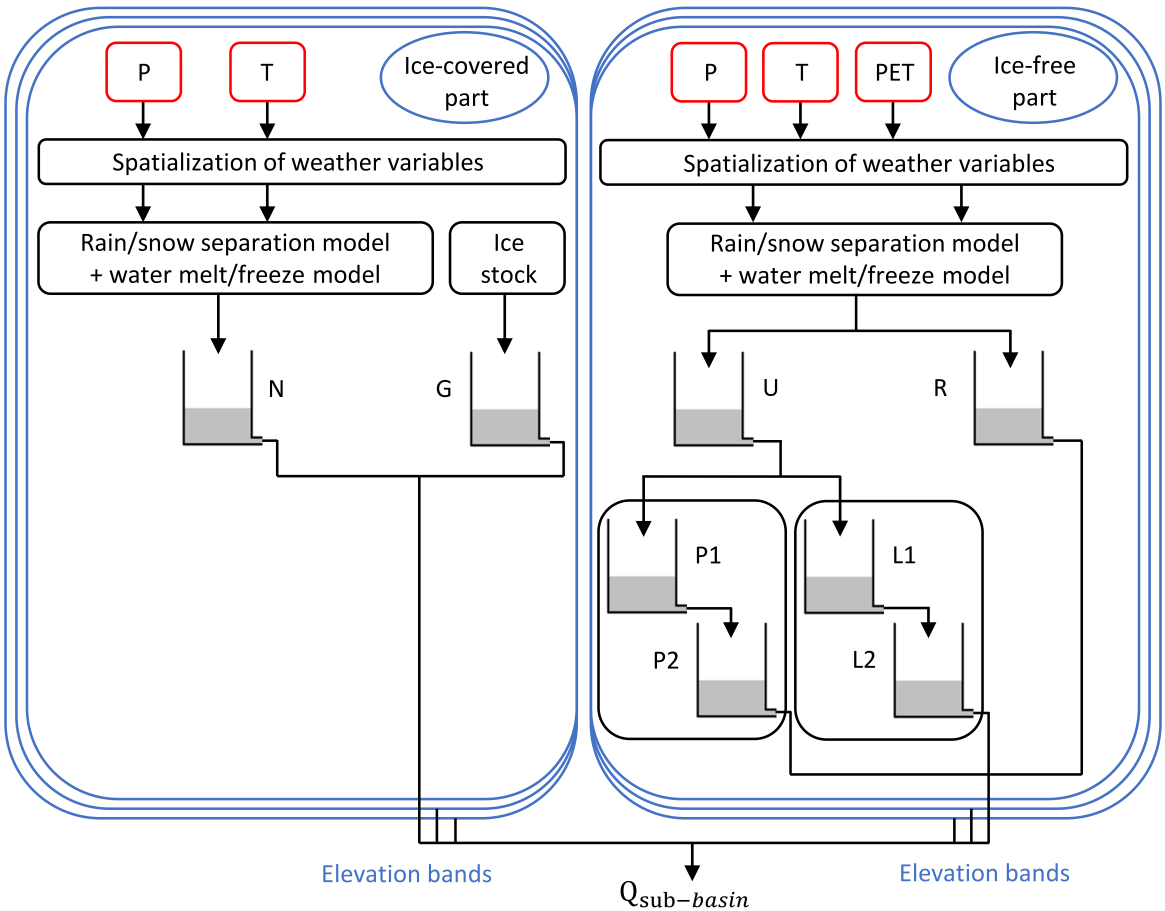

Figure S1. Scheme of the glacio-hydrological model GSM-SOCONT. The model uses daily data on precipitation (P), mean temperature (T) and potential evapotranspiration (PET) as inputs. A snow reservoir N represents the stock of snow that evolves through the processes of snow accumulation, melting and refreezing. The ice reservoir G models ice melt. Infiltration and evapotranspiration losses are simulated with a superficial reservoir U. River flow from runoff (by infiltration capacity excess) is simulated with a non-linear surface reservoir R. A Nash-like cascade of two linear reservoirs (L1 and L2) is used to simulate sub-superficial storage and release. A Nash-like cascade of two linear reservoirs (P1 and P2) is used to simulate deep groundwater storage and release.

Table S1. Calibration characteristics for each sub-basin and values of the components of the objective functions used for the automatic calibration of the hydrological model. NSE_{chrono} and NSE_{regime} correspond to the Nash-Sutcliffe Efficiency criterion applied to the discharges time series and the interannual daily regimes respectively. d_{KS} is the Kolmogorov-Smirnov distance, i.e. the maximum difference between the simulated and observed distributions of the annual daily discharge maxima. Fd_{KS} refers to the second part of the objective function $F_{altered}$ in Eq. (2). Rhône@Genève, HDI: Rhône@Genève, Halle-de-l'Ile. Rhône@Genève, BDM: Rhône@Genève, Bout-du-Monde.

Sub-basins	Gauging station	Calibration type	Calibration period(s)	NSE_{chrono}	NSE_{regime}	d_{KS}	Fd_{KS}
1	Rhône@Brigue	Chronological	1965-2015 for obs/sim	0.82	-	-	-
2	Rhône@Viège	Climatological	1922-1963 for obs 1961-2015 for sim	-	0.99	48	0.17
3, 4	Rhône@Sion	Climatological	1916-1956 for obs 1961-2015 for sim	-	0.98	163	0.19
5	Rhône@Branson	Climatological	1941-1956 for obs 1961-2015 for sim	-	0.33	45	0.32
6, 7	Rhône@Porte-du-Scex	Climatological	1941-1956 for obs 1961-2015 for sim	-	0.93	35	0.12
8, 9, 10, 11, 12	Rhône@Genève, HDI	Chronological	1961-1970 for obs/sim	0.72	-	-	-
13	Arve@Sallanches	Chronological	1965-2015 for obs/sim	0.67	-	-	-
14	Arve@Taninges	Chronological	1961-2015 for obs/sim	0.65	-	-	-
15, 16	Arve@Genève, BDM	Chronological	1965-2015 for obs/sim	0.44	-	-	-
17, 18	Rhône@Bognes	Climatological	1923-1947 for obs 1961-2015 for sim	-	0.33	62	0.10

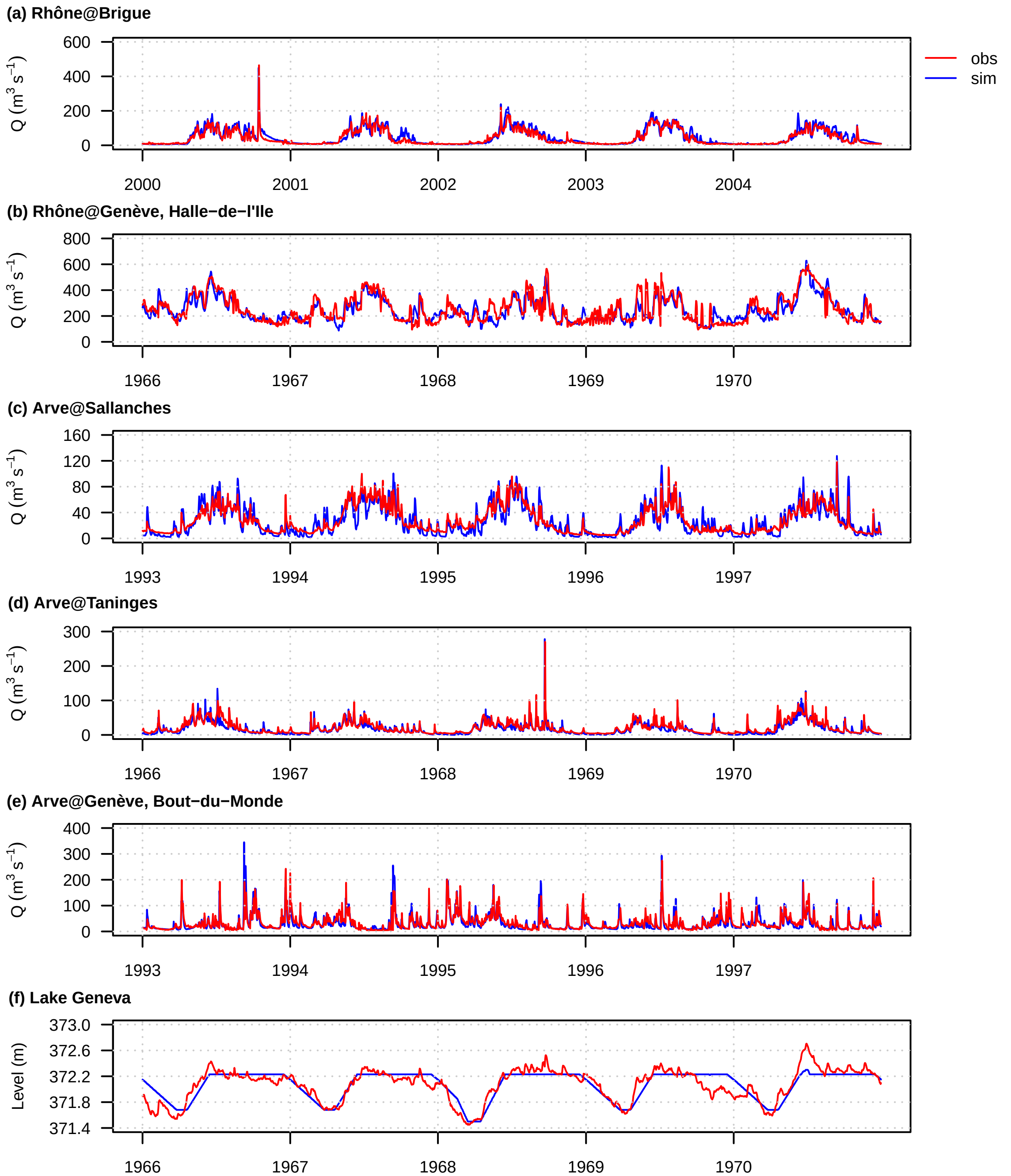

Figure S2. Classical calibration of sub-basins that present a natural (or at least not significantly altered) hydrological regime. **(a)** Rhône@Brigue (1965-2015). **(b)** Rhône@Genève, Halle-de-l'Ile (1961-1970). **(c)** Arve@Sallanches (1965-2015). **(d)** Arve@Taninges (1961-2015). **(e)** Arve@Genève, Bout-du-Monde (1965-2015). **(f)** Example of Lake Geneva levels observed and simulated over the same period as discharges at Rhône@Genève, Halle-de-l'Ile. The calibration criterion is the NSE coefficient calculated from the observed and simulated time series of discharge at the sub-basin outlet.

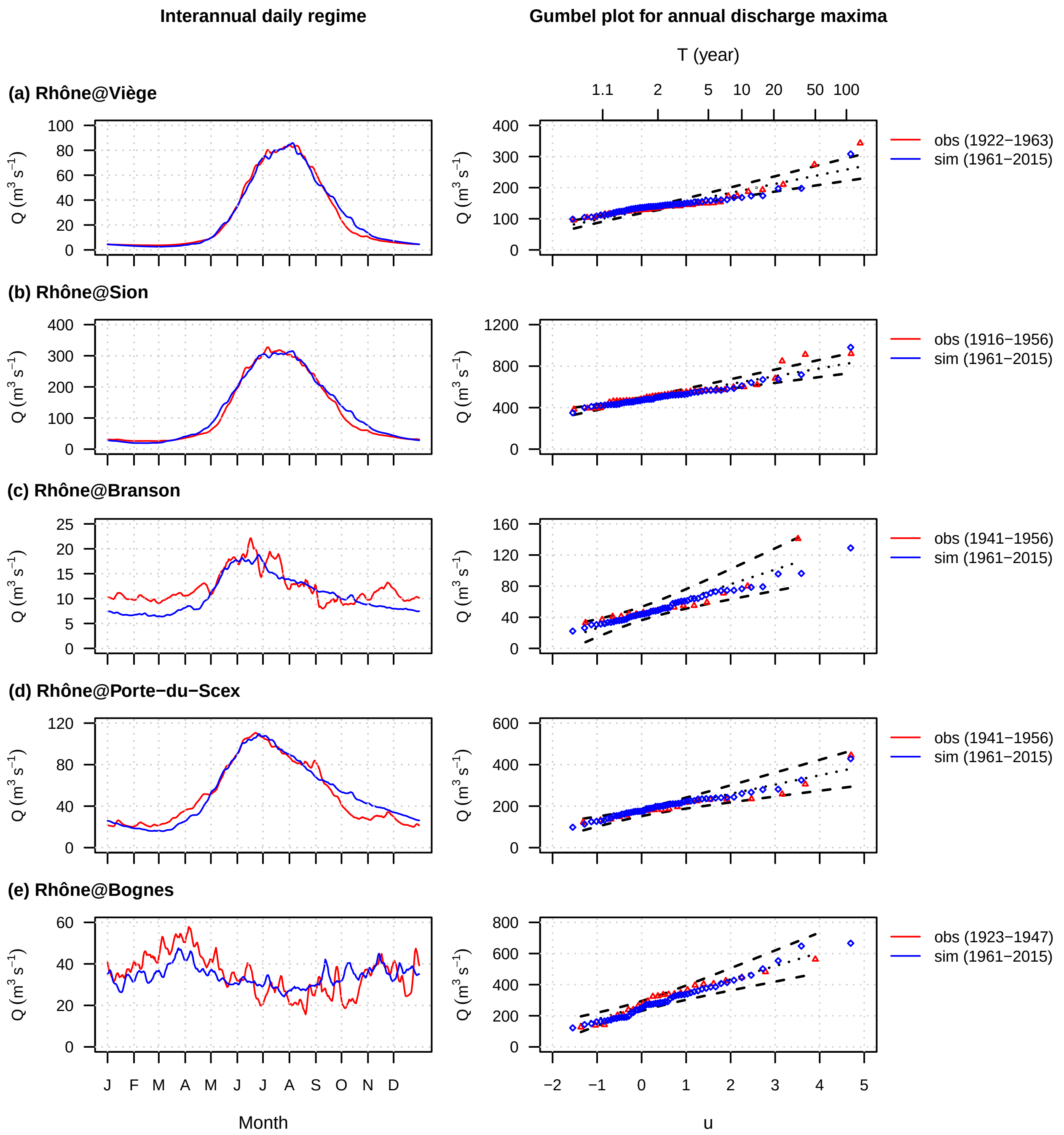

Figure S3. Signatures-based calibration of sub-basins that present an altered hydrological regime. **(a)** Rhône@Viège. **(b)** Rhône@Sion. **(c)** Rhône@Branson. **(d)** Rhône@Porte-du-Scex. **(e)** Rhône@Bognes. **(left)** Interannual daily regime. (**right**) Gumbel plot for annual daily discharge maxima. The x-axis is the reduced variate u for the given return period T, i.e. $u = -\ln(-\ln(1-1/T))$. Dashed lines correspond to 90 % confidence bounds of the Gumbel distribution estimated on observed data. The calibration criteria are the NSE coefficient between simulated and observed regimes and the Kolmogorov-Smirnov coefficient between the observed and the simulated distributions of annual daily discharge maxima.

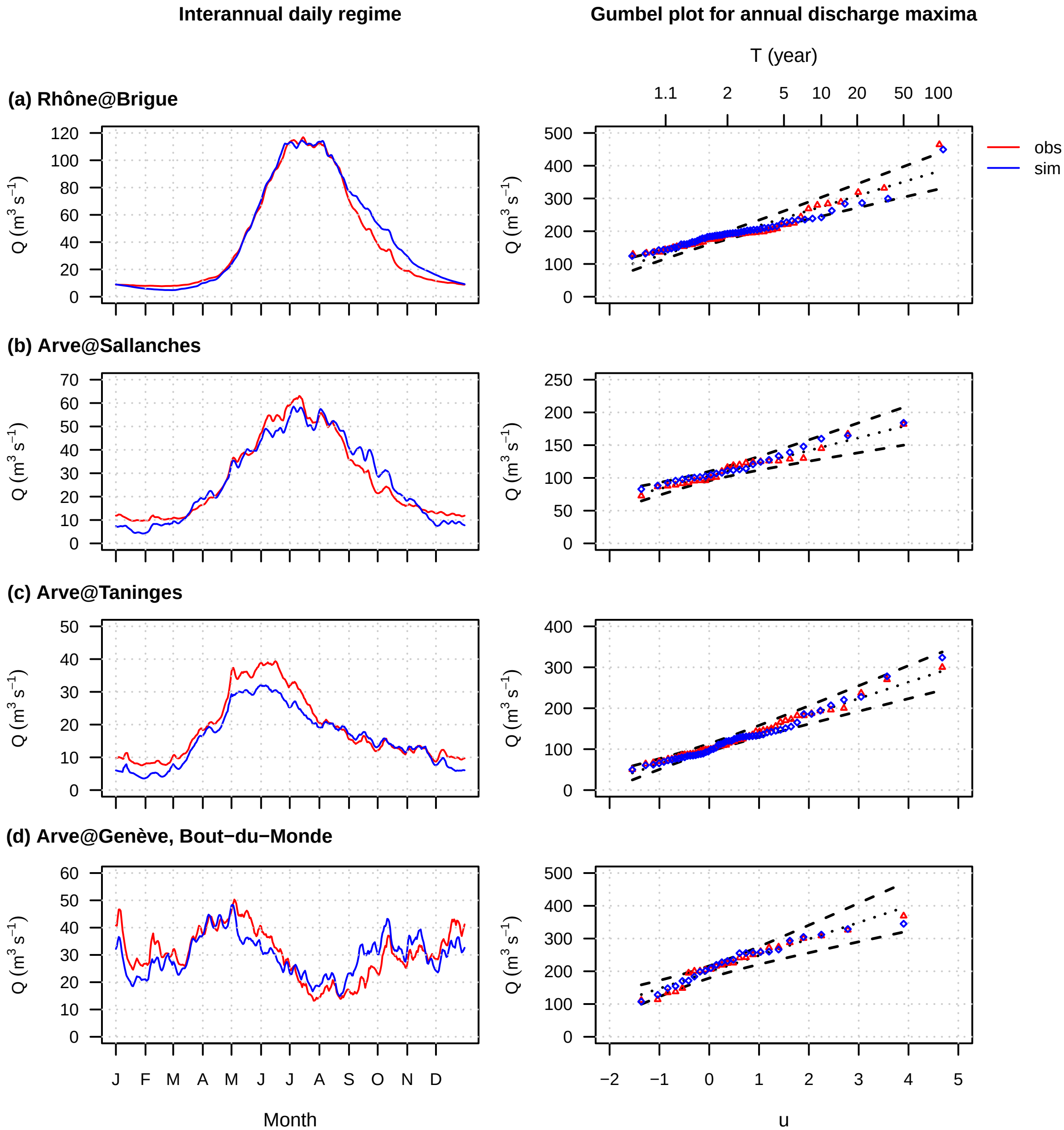

Figure S4. Signatures-based calibration of sub-basins that present a natural (or at least not significantly altered) hydrological regime. **(a)** Rhône@Brigue (1965-2015). **(b)** Arve@Sallanches (1965-2015). **(c)** Arve@Taninges (1961-2015). **(d)** Arve@Genève, Bout-du-Monde (1965-2015). **(left)** Interannual daily regime. (**right**) Gumbel plot for annual daily discharge maxima. The x-axis is the reduced variate u for the given return period T, i.e. $\mathrm{u} = -\ln(-\ln(1-1/\mathrm{T}))$. Dashed lines correspond to 90 % confidence bounds of the Gumbel distribution estimated on observed data. The calibration criteria are the NSE coefficient between simulated and observed regimes and the Kolmogorov-Smirnov coefficient between the observed and the simulated distributions of annual daily discharge maxima.

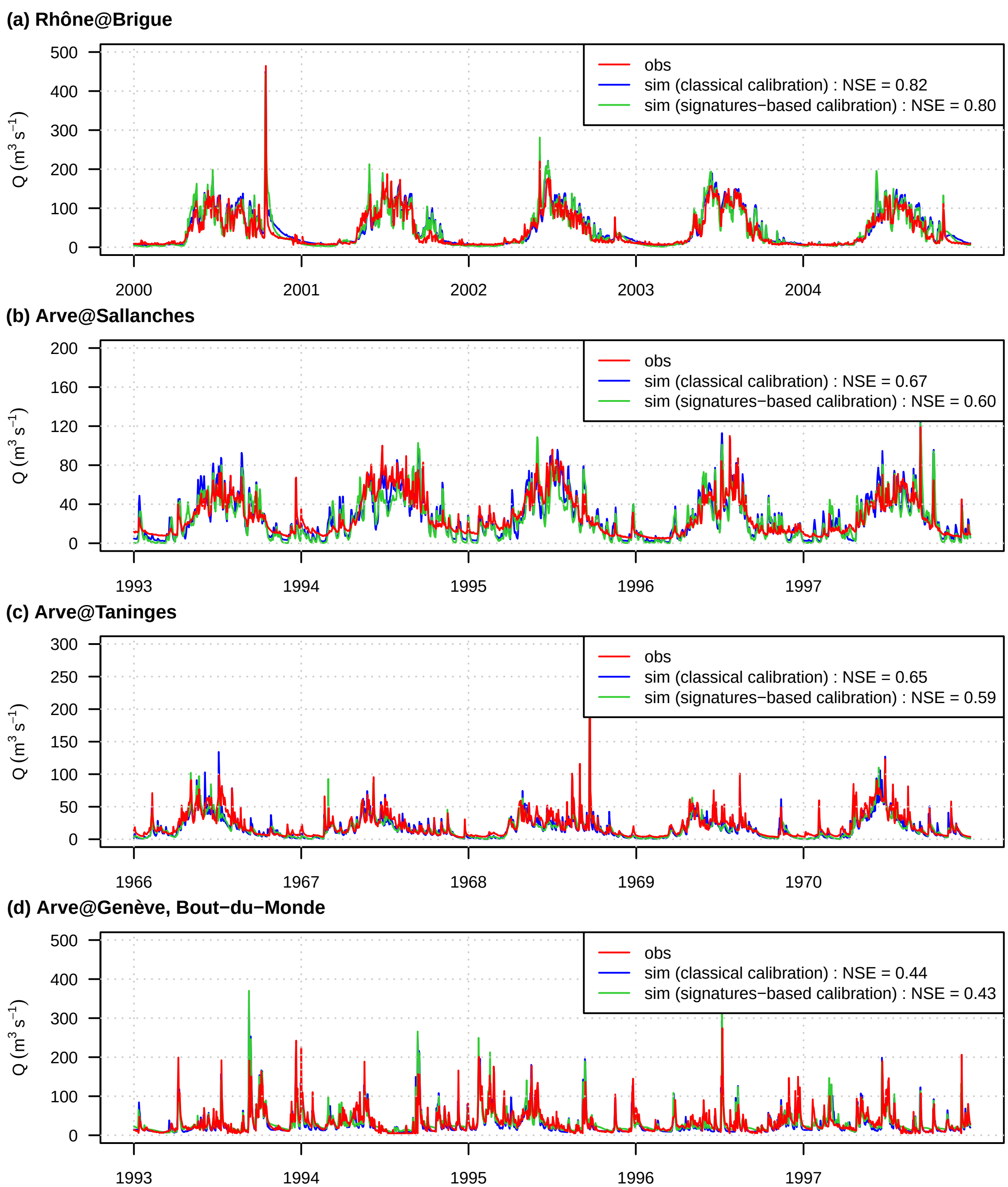

Figure S5. Comparison of the two types of calibration for sub-basins that present a natural (or at least not significantly altered) hydrological regime. The NSE coefficients were calculated using discharges data from the same period for both types of calibration: classical calibration and signatures-based calibration. **(a)** Rhône@Brigue (1965-2015). **(b)** Arve@Sallanches (1965-2015). **(c)** Arve@Taninges (1961-2015). **(d)** Arve@Genève, Bout-du-Monde (1965-2015).

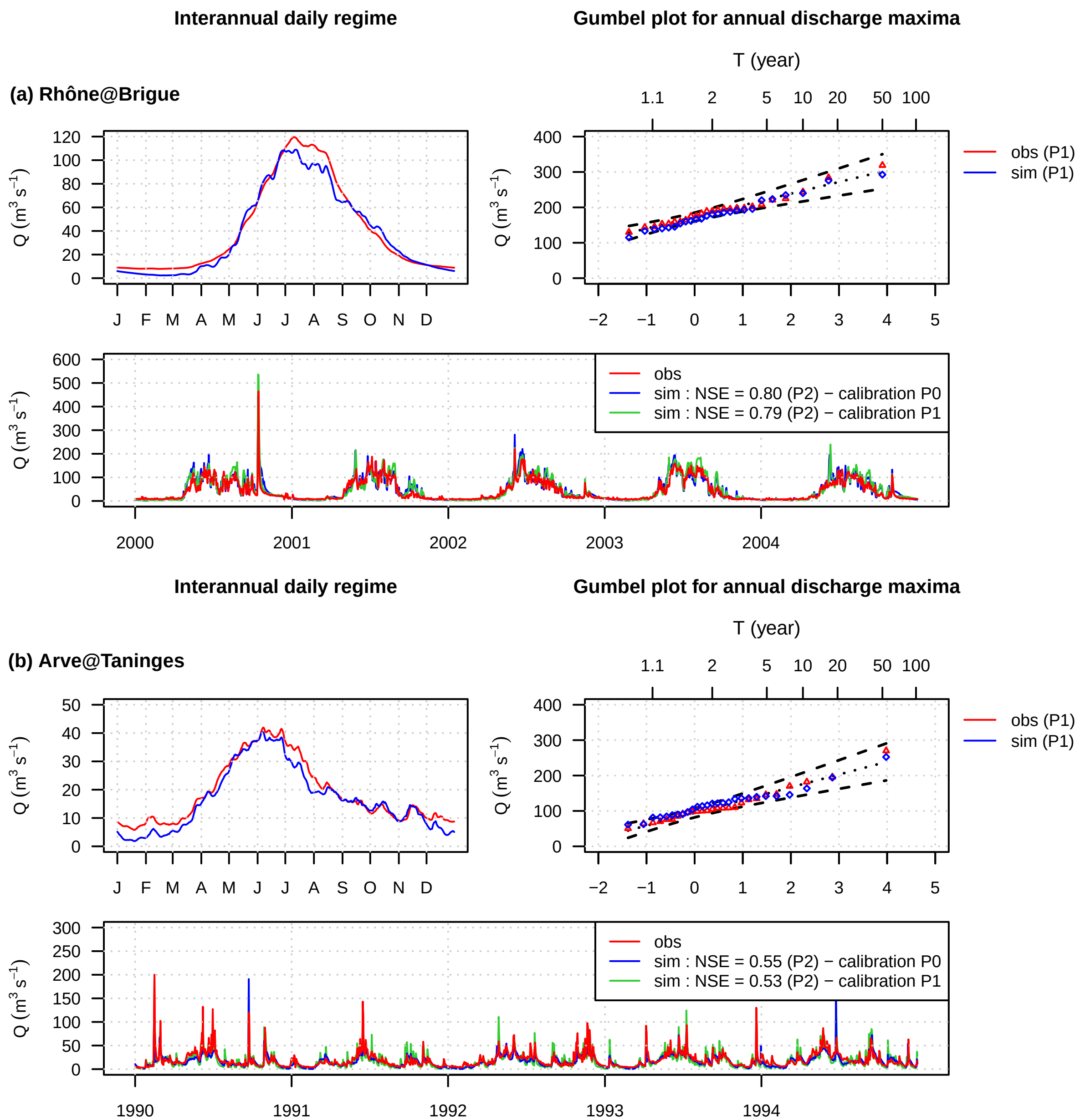

Figure S6. Calibration-validation procedure applied to two sub-basins that present a natural (or at least not significantly altered) hydrological regime. The signature-based calibration was applied to the signatures of period P1 with weather data from P1. The signatures are the interannual daily regime and the statistical distribution of the annual daily discharge maxima. The discharge time series obtained with this signature-based calibration is shown along with those observed and those obtained from calibration based on the signatures of the entire period P0. The NSE coefficients were calculated from the observed and simulated time series of discharge over the period P2 from the weather data of P2. **(a)** Rhône@Brigue: P0 = 1965-2015, P1 = 1965-1989, P2 = 1991-2015. **(b)** Arve@Taninges: P0 = 1961-2015, P1 = 1961-1987, P2 = 1989-2015.

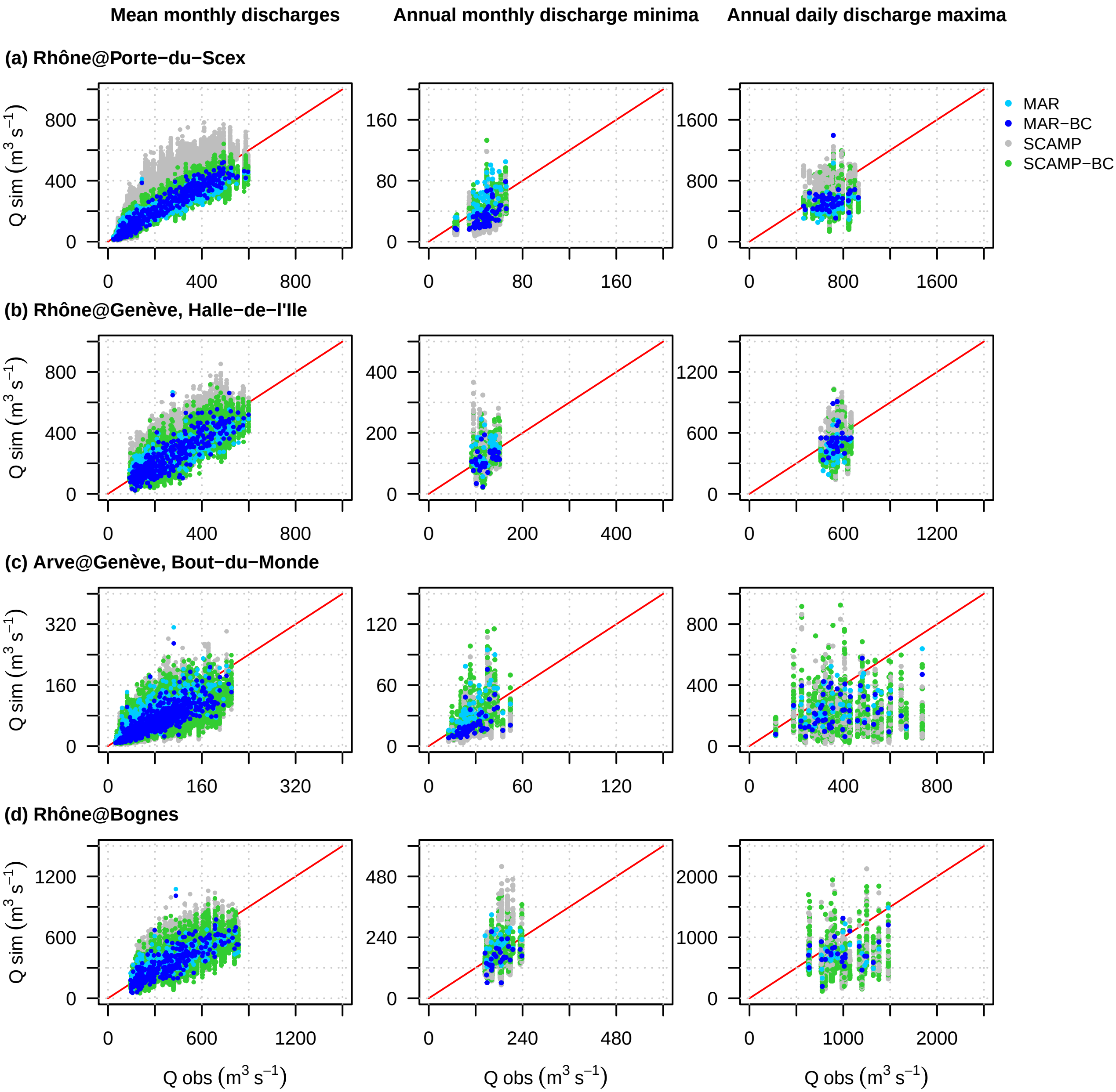

Figure S7. Scatter plots of mean monthly discharges, annual monthly discharge minima and annual daily discharge maxima at (**a**) Rhône@Porte-du-Scex (1905-1956), (**b**) Rhône@Genève, Halle-de-l'Ile (1923-1956), (**c**) Arve@Genève, Bout-du-Monde (1904-1960), and (**d**) Rhône@Bognes (1920-1947). Q obs: observed discharge. MAR/MAR-BC: simulated discharge from the raw/bias-corrected weather scenario produced with the dynamical downscaling model MAR. SCAMP/SCAMP-BC: simulated discharge from the raw/bias-corrected weather scenarios produced with the statistical downscaling model SCAMP.

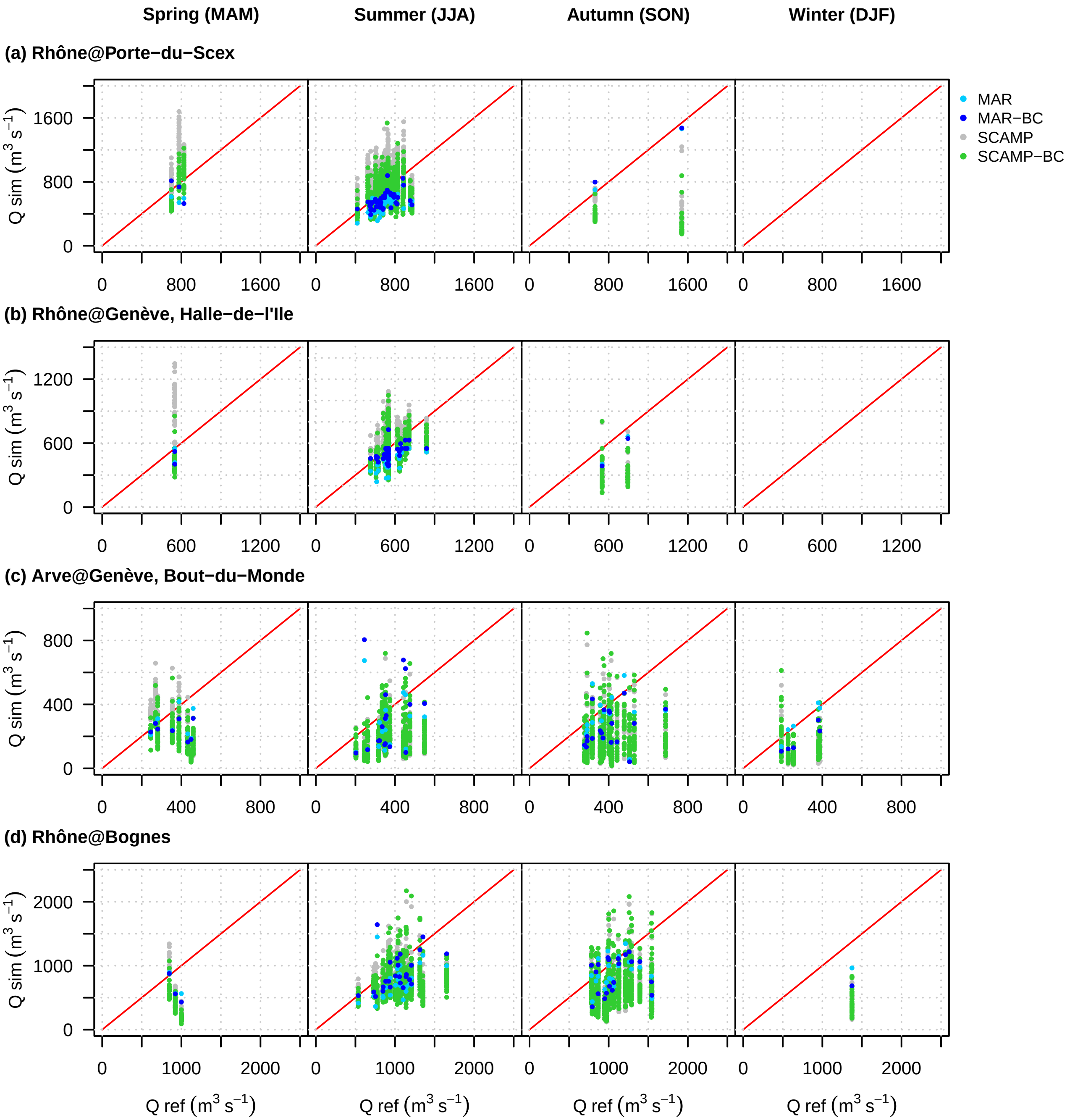

Figure S8. Scatter plots of annual daily discharge maxima by season at (**a**) Rhône@Porte-du-Scex, (**b**) Rhône@Genève, Halle-de-l'Ile, (**c**) Arve@Genève, Bout-du-Monde, and (**d**) Rhône@Bognes for the 1961-2009 period. MAM: March-April-May. JJA: June-July-August. SON: September-October-November. DJF: December-January-February. Q ref: simulated discharge from observed weather variables. MAR/MAR-BC: simulated discharge from the raw/bias-corrected weather scenario produced with the dynamical downscaling model MAR. SCAMP/SCAMP-BC: simulated discharge from the raw/bias-corrected weather scenarios produced with the statistical downscaling model SCAMP.

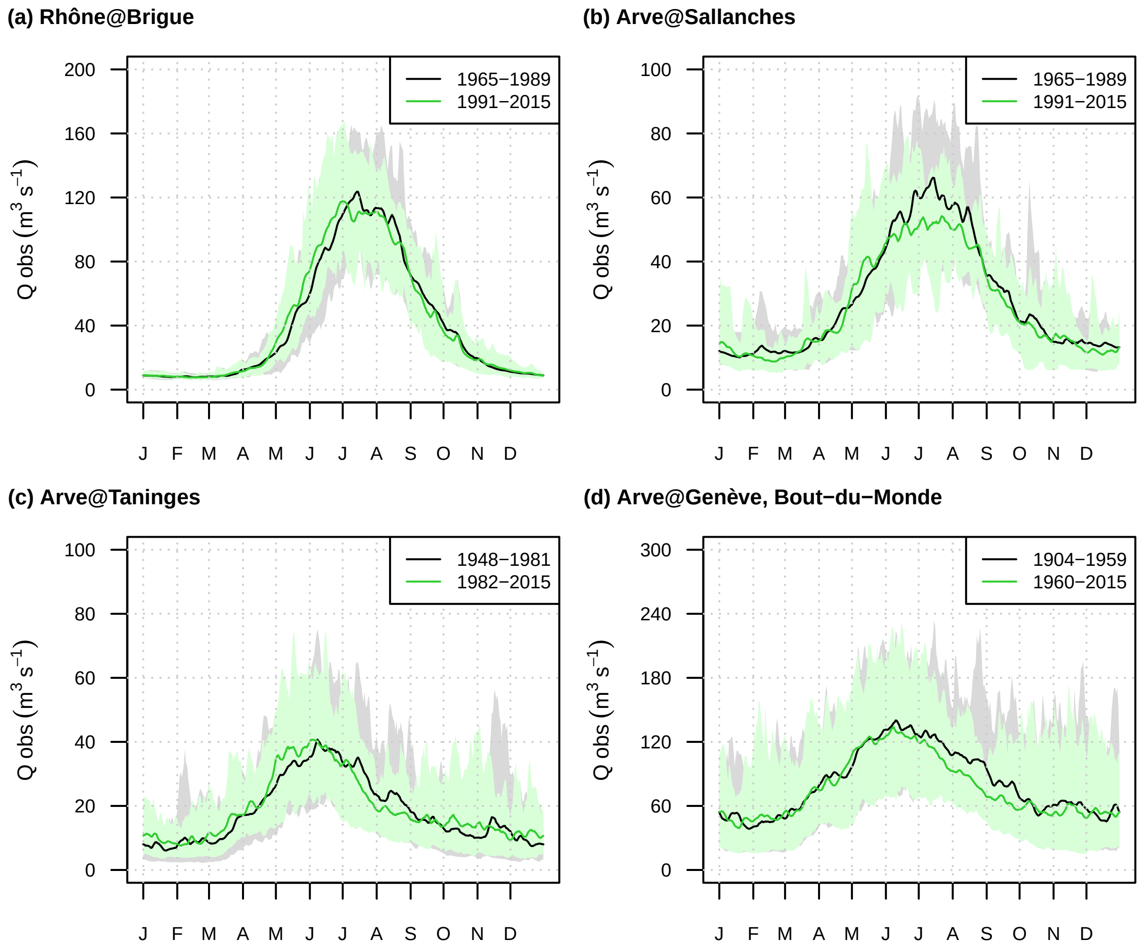

Figure S9. Assessment of the stationarity assumption of the natural hydrological behavior of the Upper Rhône River catchment over the last century. For sub-basins that present a natural (or at least not significantly altered) hydrological regime, we split the period of available observed discharge data into two periods. The mean interannual daily regimes are indicated by the black and green solid lines. The grey and green bands represent the confidence intervals at 90 % level. **(a)** Rhône@Brigue. **(b)** Arve@Sallanches. **(c)** Arve@Taninges. **(d)** Arve@Genève, Bout-du-Monde.