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High-resolution satellite products improve hydrological modeling in northern Italy

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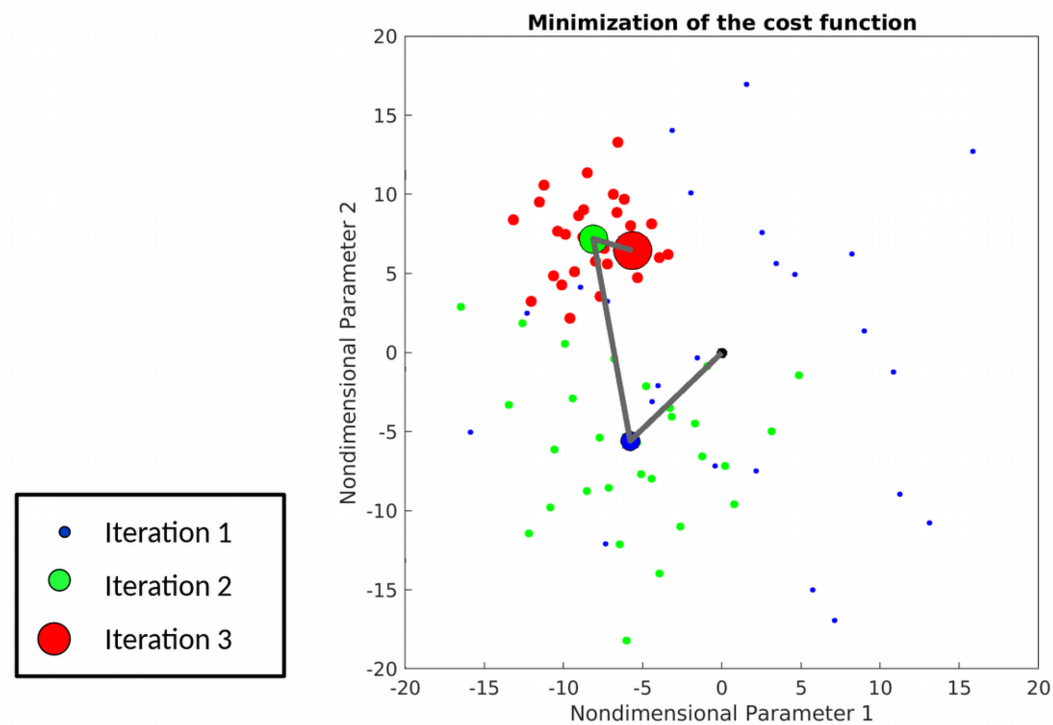

Figure S1*:* Representation of the calibration search algorithm (in a 2-dimension space). The optimal value of each gaussian exploration is used as the centre of the next one.

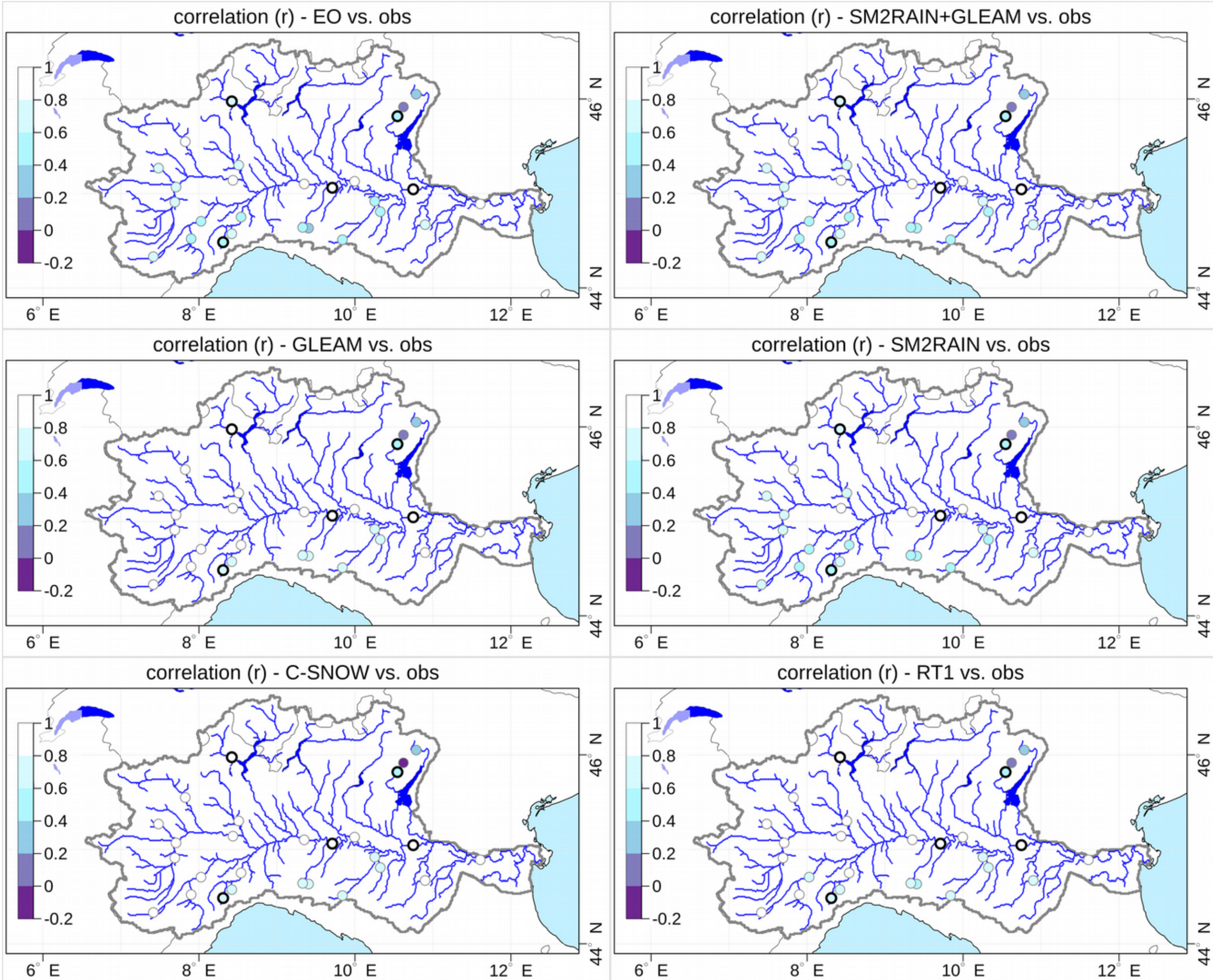

Figure S2*:* Spatial distribution of the Pearson's correlation (r) of the six model runs driven by the four input satellite products versus observed discharges at the measurement stations. Validation stations are marked with a bold circle. Multi-product experiments are in the first row, while single-product experiments in row 2 (forcing input) and 3 (data assimilation input).

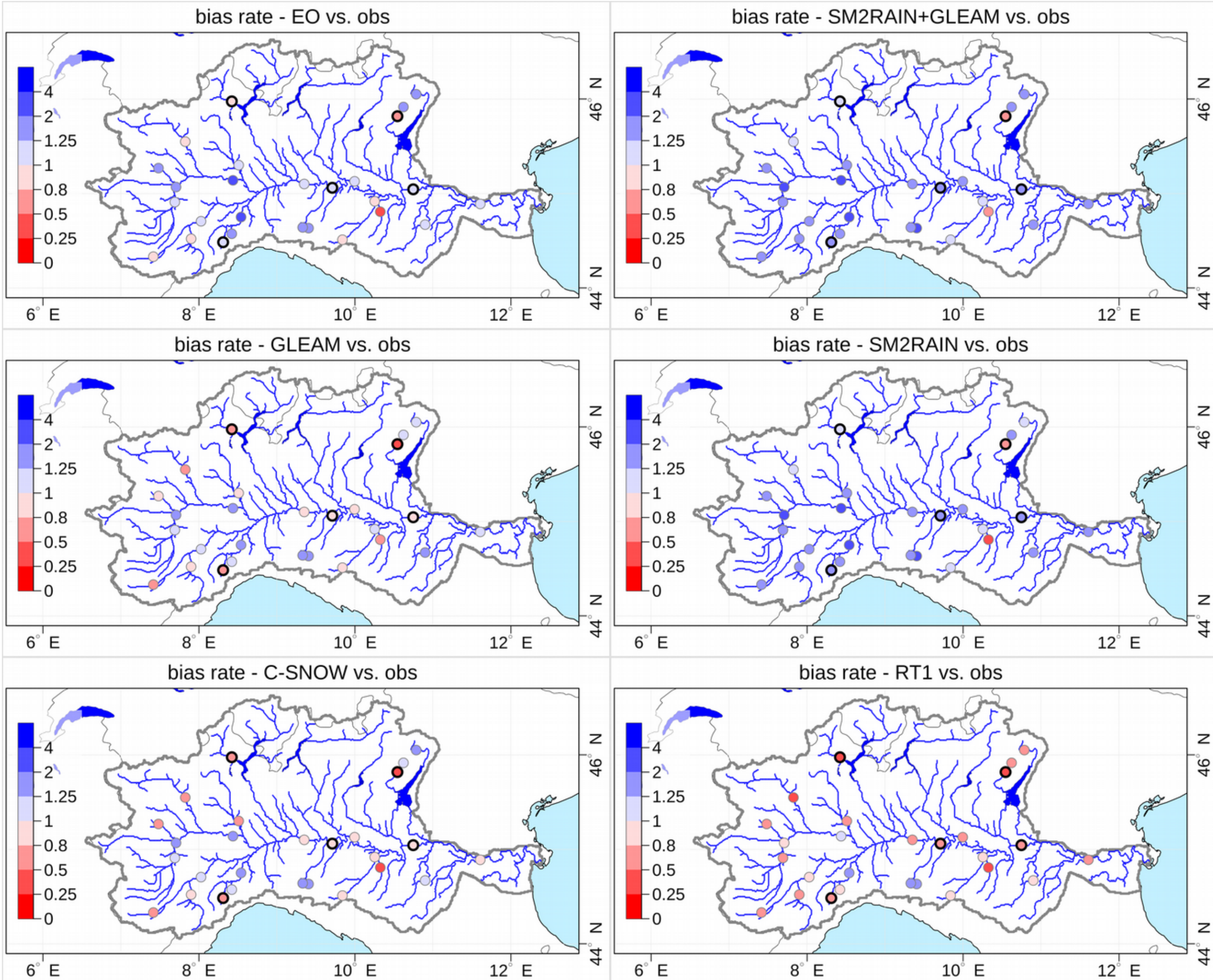

Figure S3*:* Like Figure S2 for the bias rate at the measurement stations.

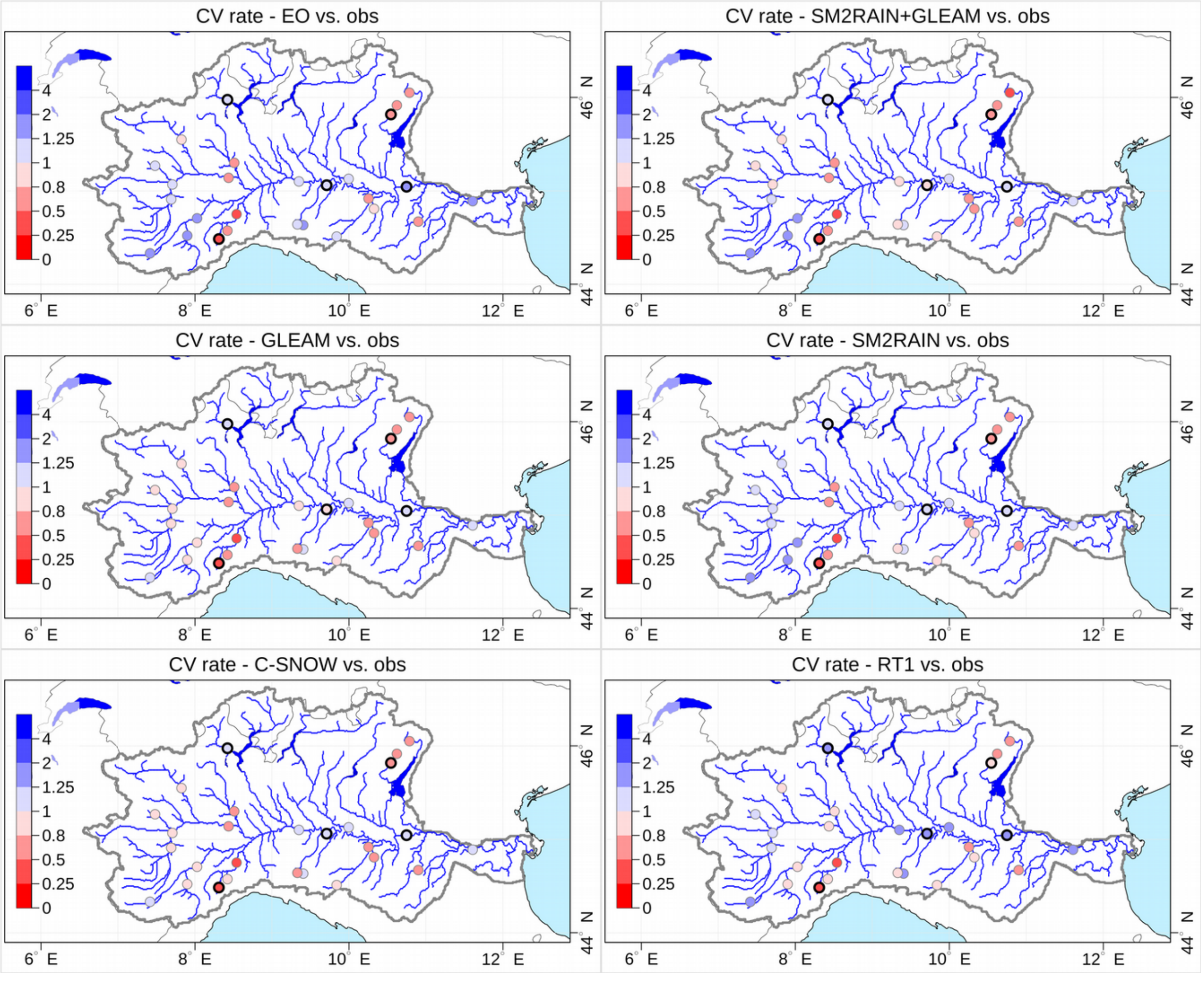

Figure S4*:* Like Figure S2 for the the Coefficient of Variation rate (CV rate) at the measurement stations.

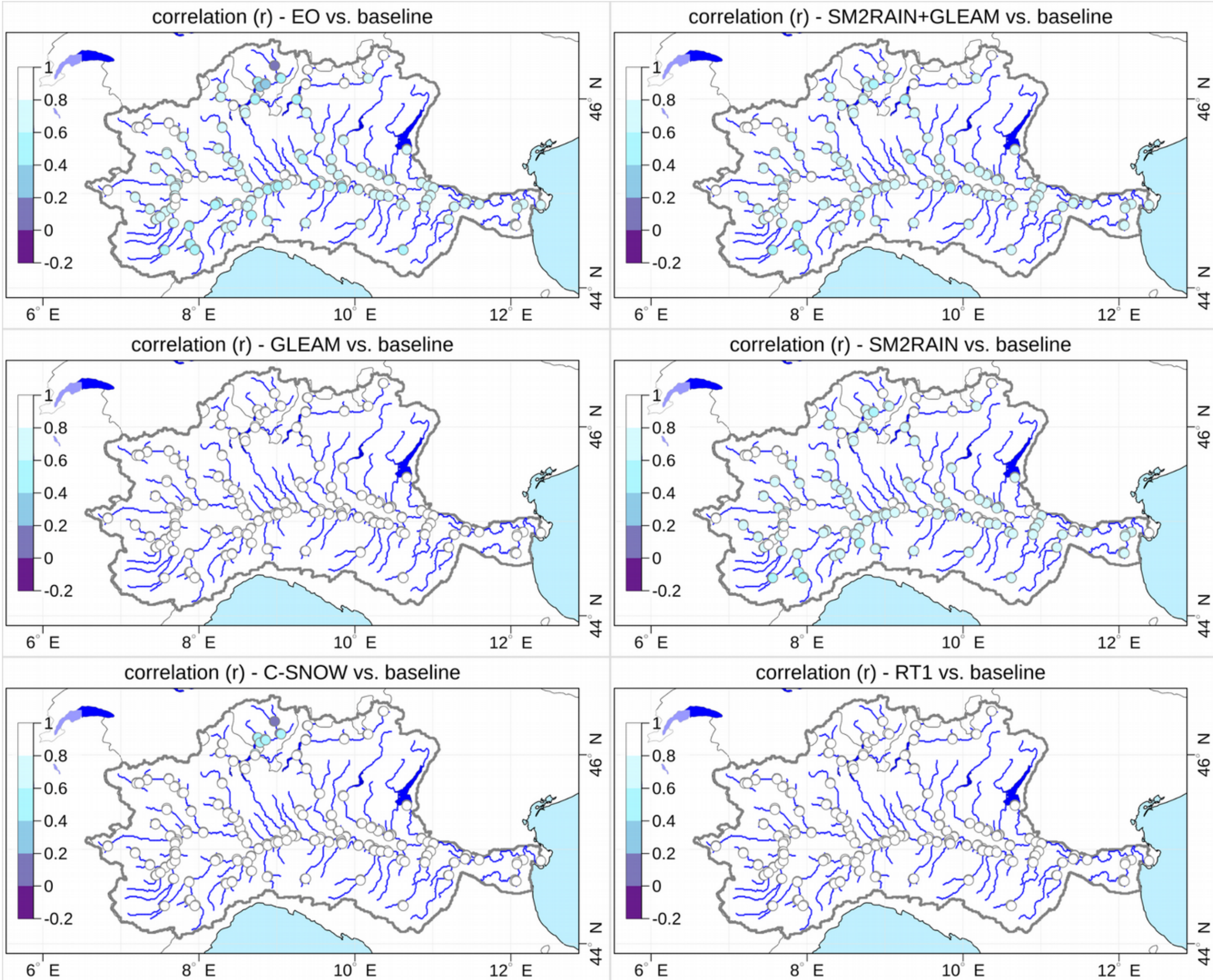

Figure S5*:* Spatial distribution of the correlation (r) of the six model runs driven by the four input satellite products versus the baseline simulation at each modeled river reach. Multi-product experiments are in the first row, while single-product experiments in row 2 (forcing input) and 3 (data assimilation input).

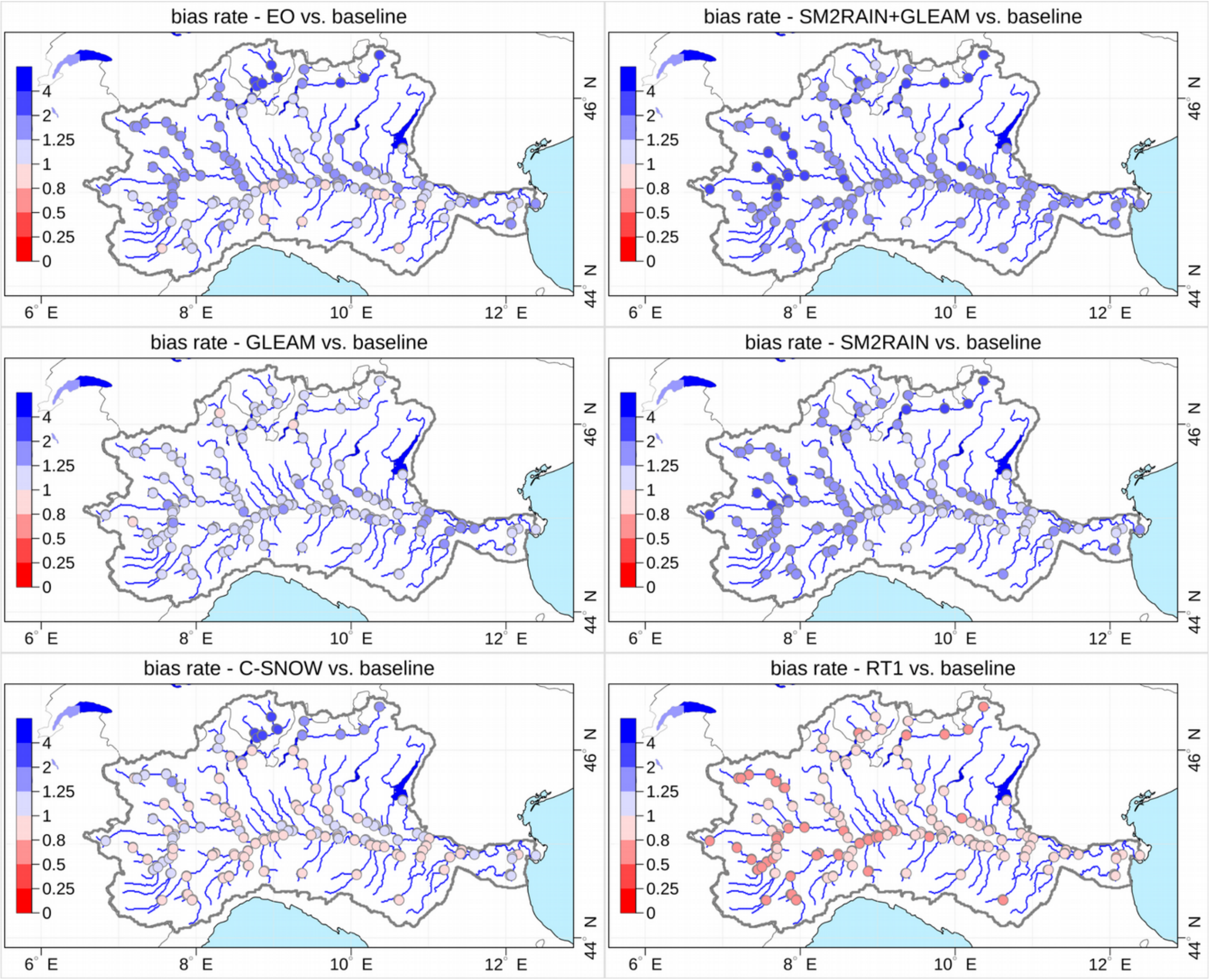

Figure S6*:* Like Figure S5 for the bias rate at each modeled river reach.

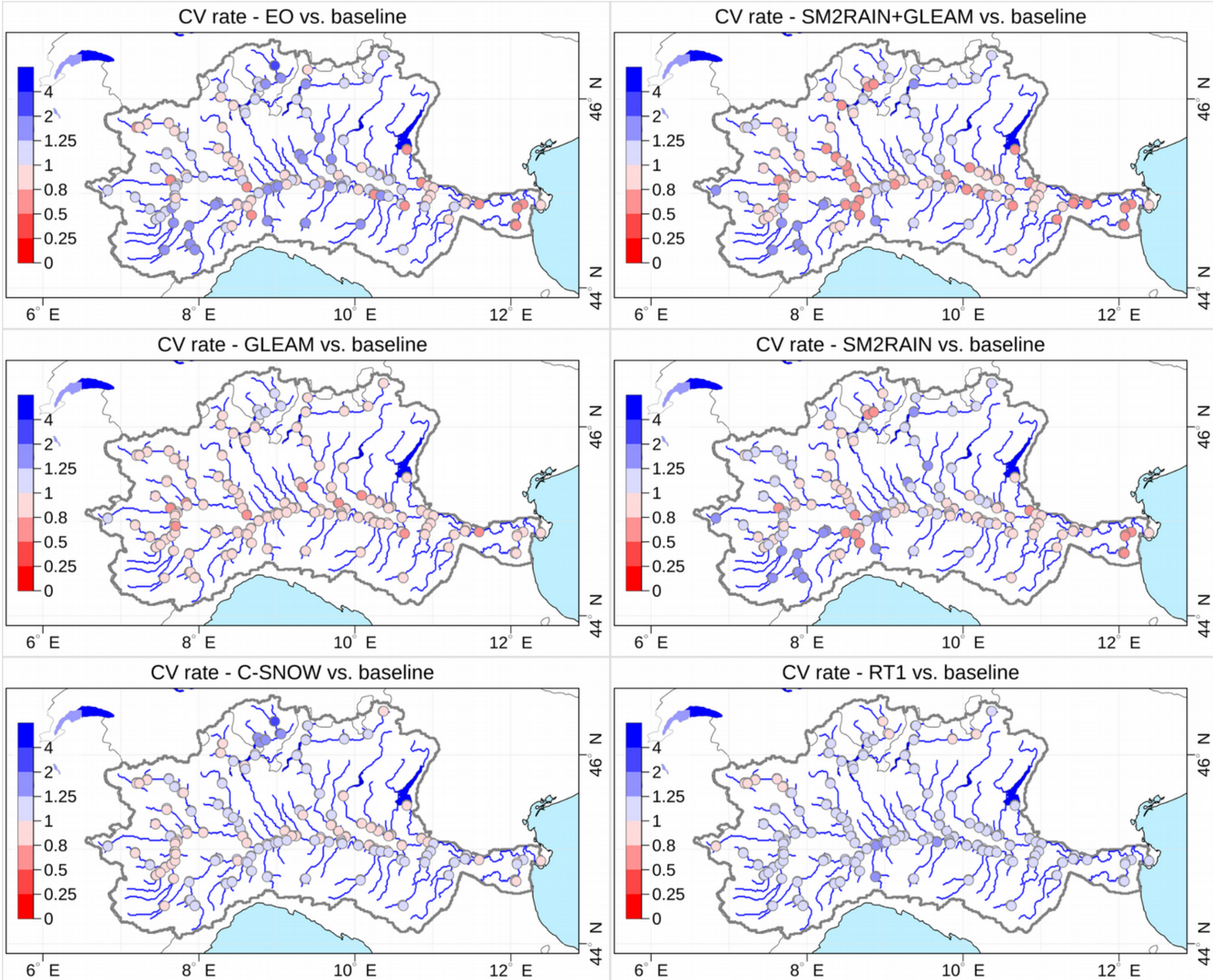

Figure S7: Like Figure S5 for the coefficient of variation rate (CV rate) at each modeled river reach.

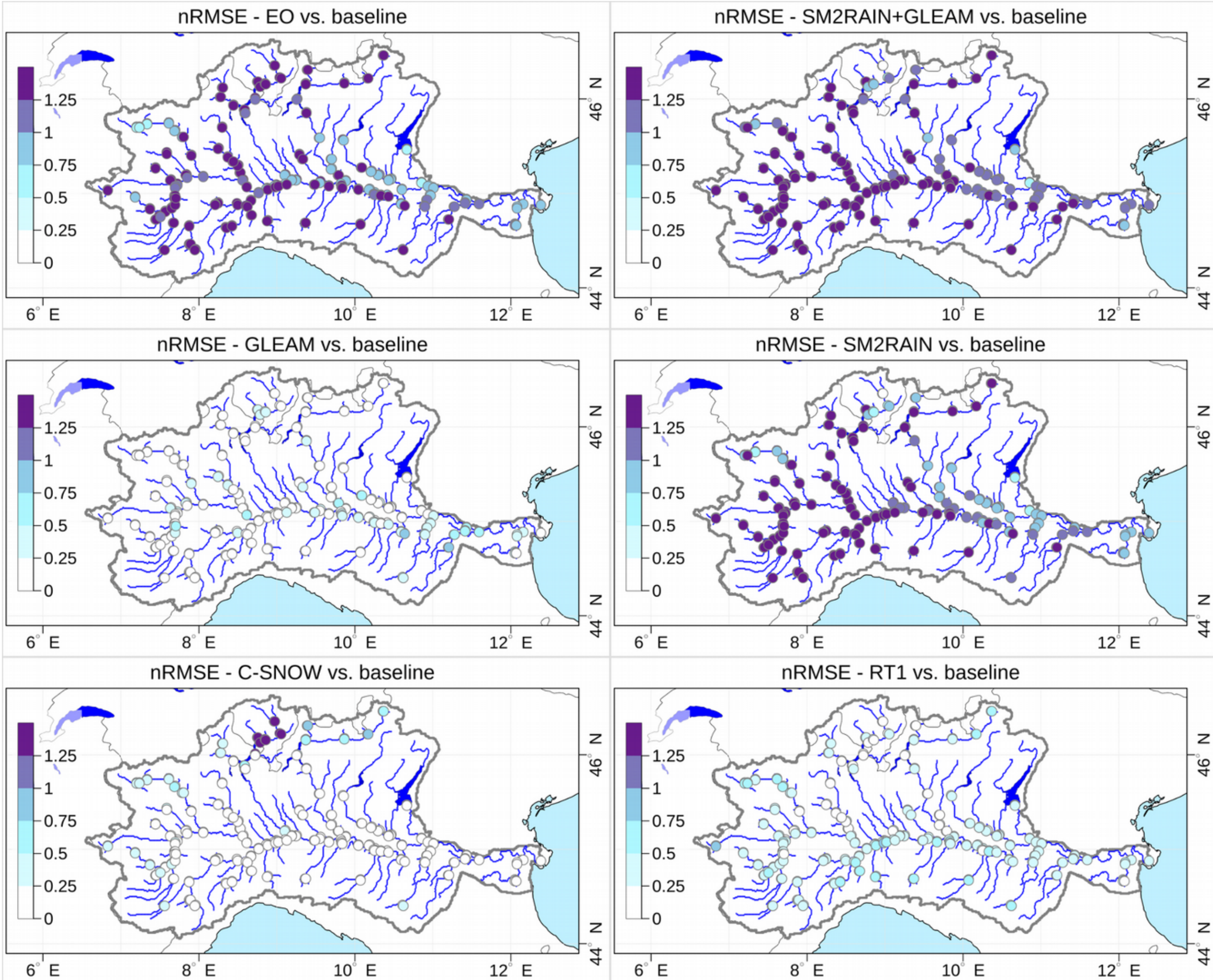

Figure S8*:* Like Figure S5 for the normalized root mean square error (nRMSE) at each modeled river reach.

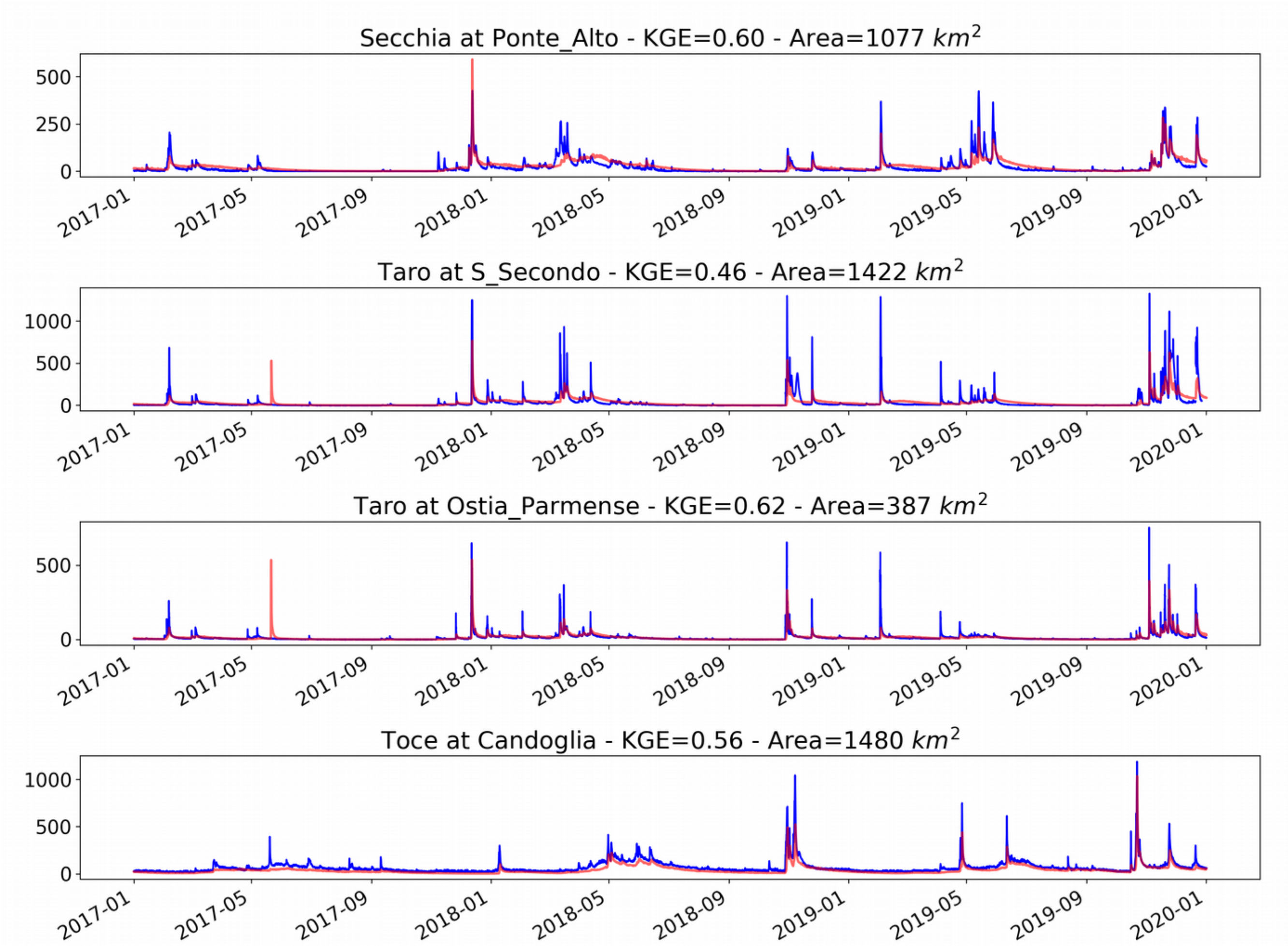

Figure S9*:* Observed versus simulated (baseline) discharge [m^3/s] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

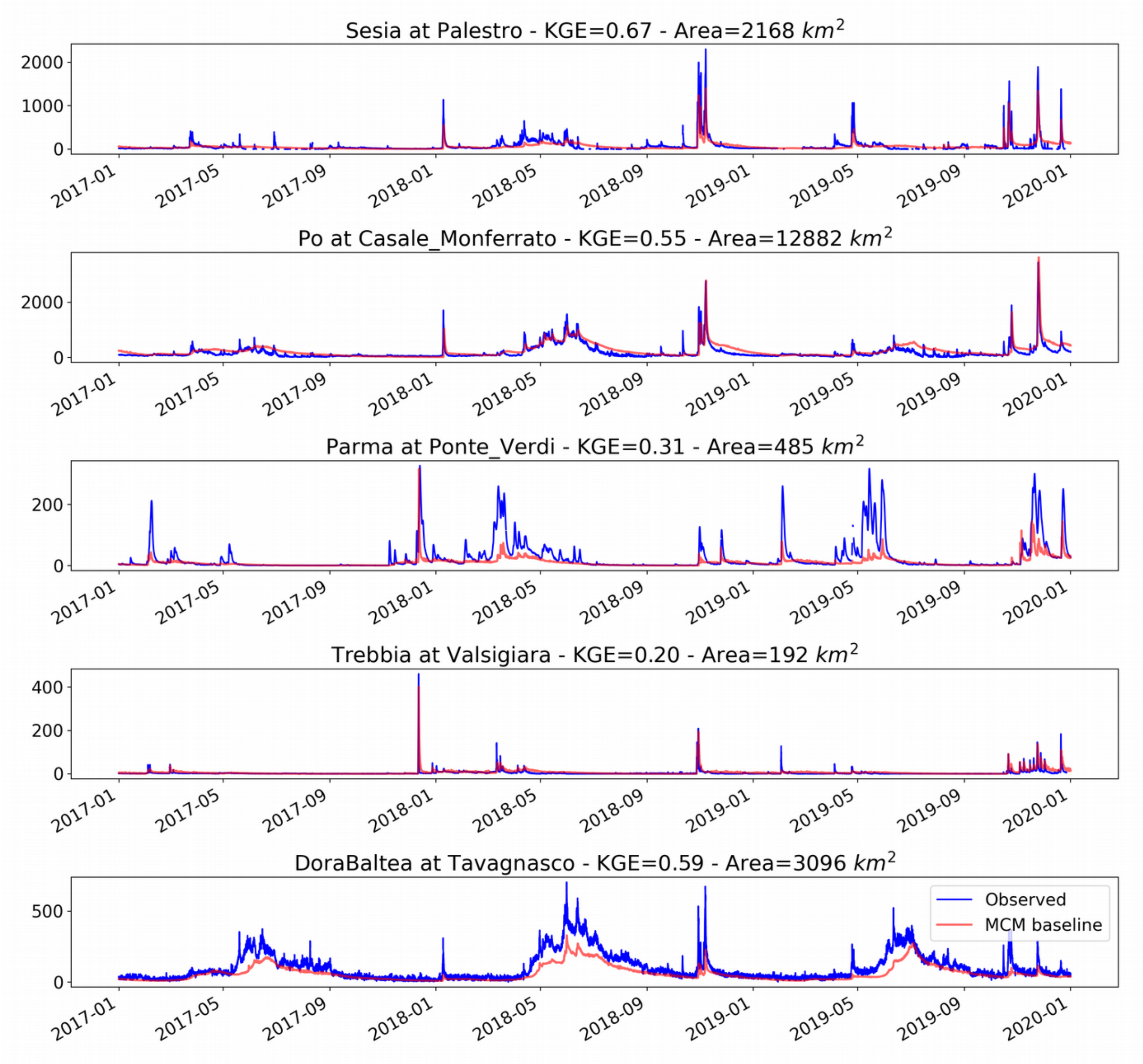

Figure S9 (continued)*:* Observed versus simulated (baseline) discharge [m^3/s] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

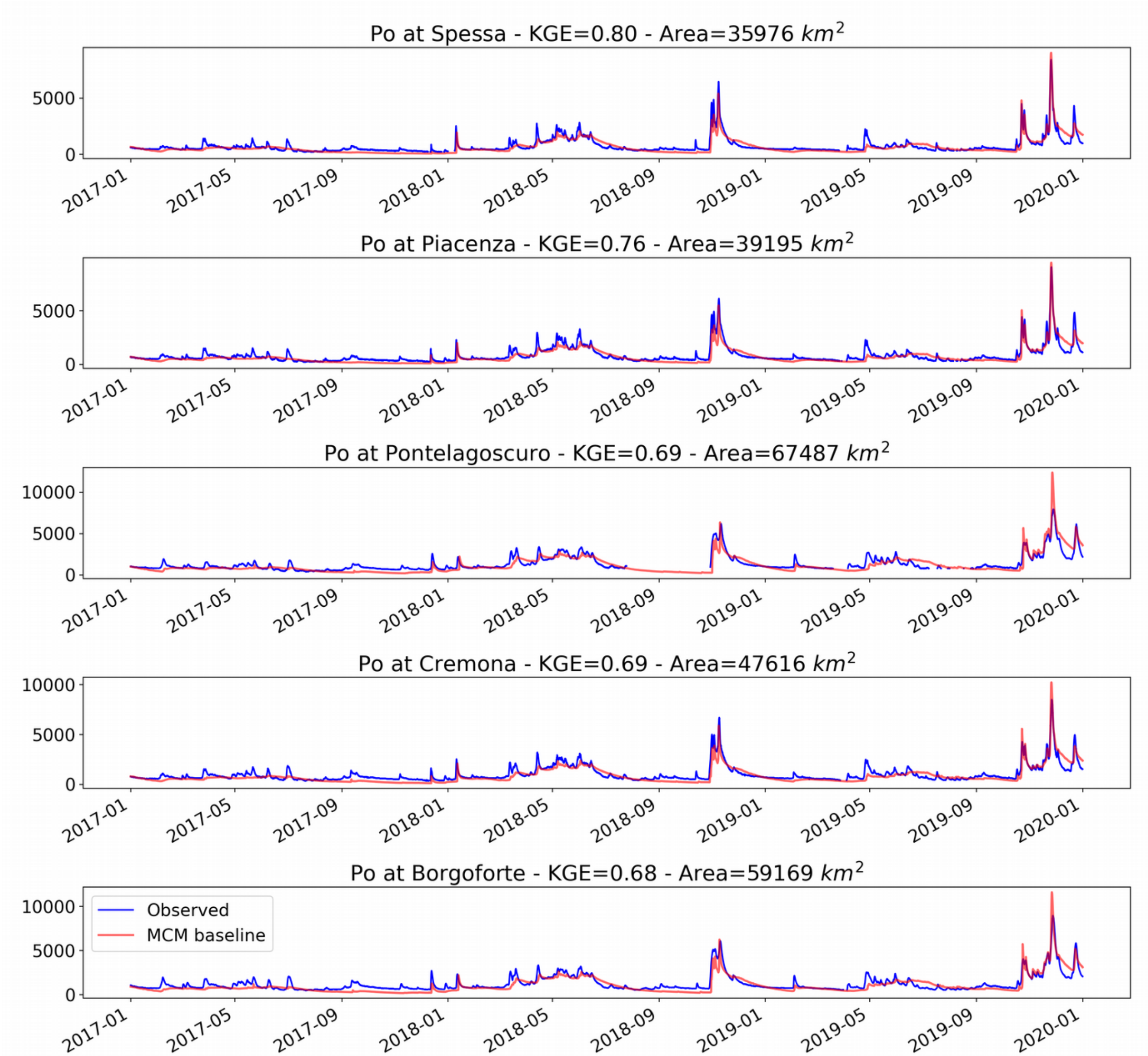

Figure S9 (continued)*:* Observed versus simulated (baseline) discharge [m^3/s] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

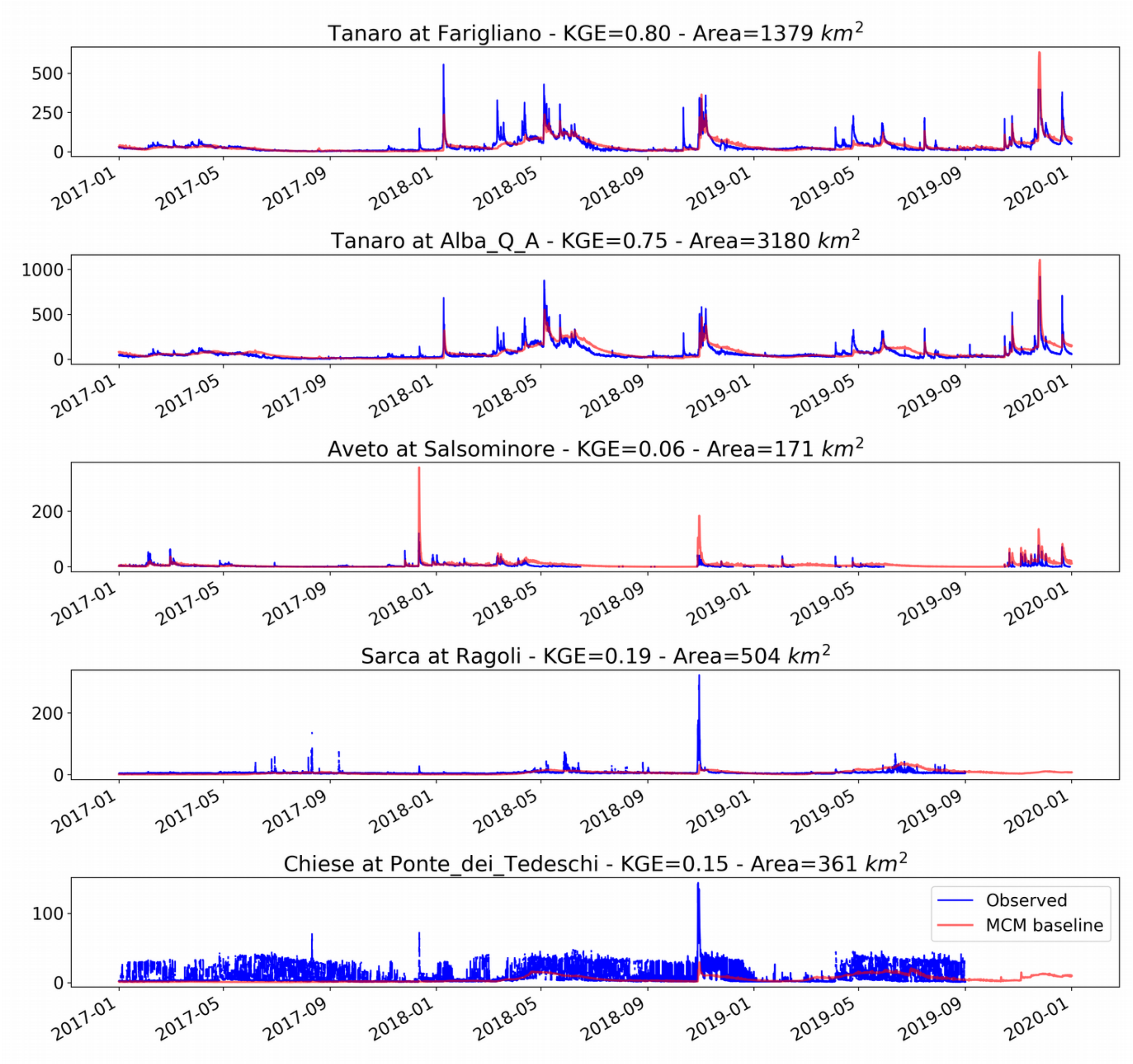

Figure S9 (continued)*:* Observed versus simulated (baseline) discharge [m^3/s] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

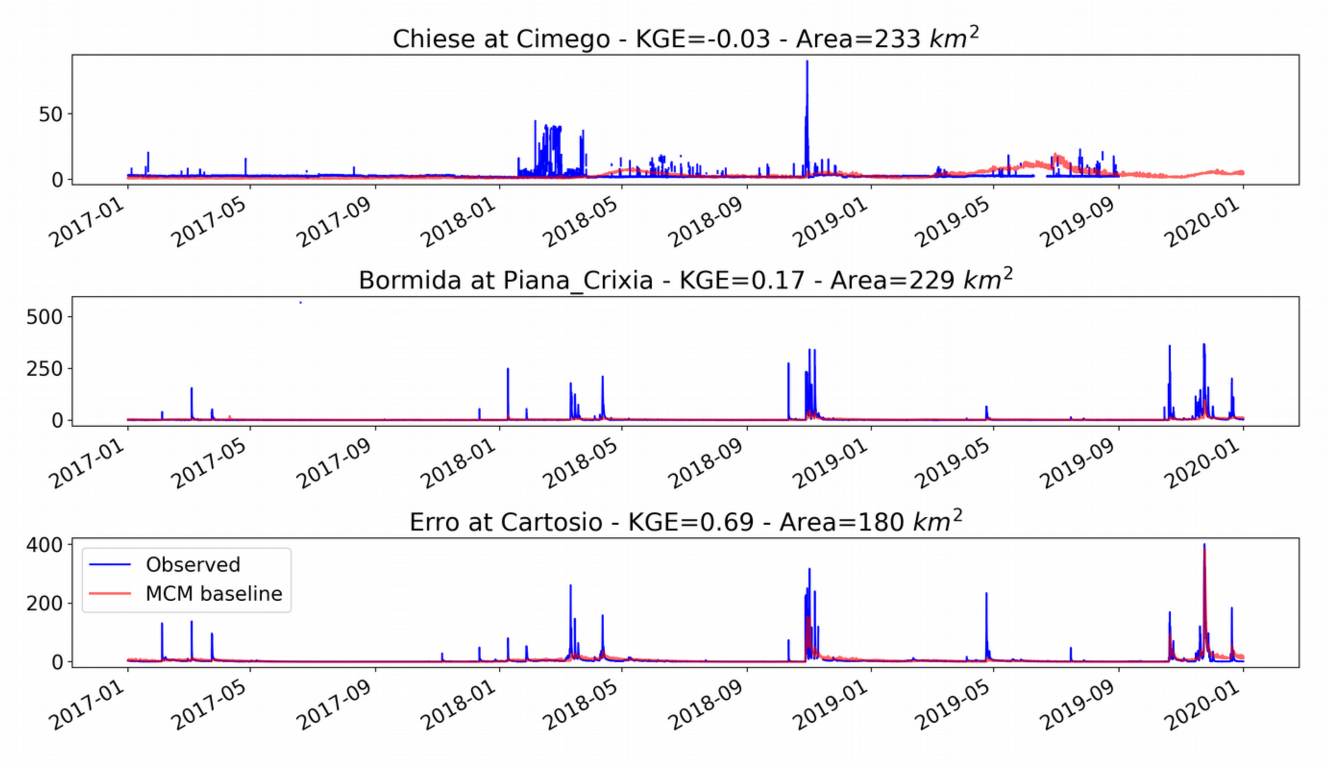

Figure S9 (continued)*:* Observed versus simulated (baseline) discharge [m^3/s] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

Table S1: Performance metrics of simulated versus observed river discharge for the five selected virtual stations: Pearson correlation (*r*), Root Mean Square Error (*RMSE*), Relative RMSE (*rRMSE*), Nash Sutcliffe Efficiency (*NSE*), Kling-Gupta Efficiency (*KGE*).

Station	*r*	*RMSE*	*rRMSE*	*NSE*	*KGE*
	[-]	[m^3/s]	[%]	[-]	[-]
Piacenza	0.80	281	40	0.65	0.75
Cremona	0.93	188	21	0.85	0.91
Borgoforte	0.92	224	21	0.85	0.91
Sermide	0.92	243	22	0.85	0.91
Pontelagoscuro	0.91	272	24	0.82	0.89

Table S2: Model performance of the baseline simulation over 2017-2019 at the calibration and validation discharge stations.

	Station	Area [km²]	KGE	r	Bias rate	CV rate	RMSE [m³/s]	ME [m³/s]
CALIBRATION	Salsominore	171	0.06	0.61	1.85	1.10	12	4
	Cartosio	180	0.69	0.78	1.05	0.78	11	0
	Valsigiara	192	0.20	0.77	1.71	0.71	10	3
	Cimego	233	-0.03	0.00	1.00	0.75	4	0
	Ostia_Parmense	387	0.62	0.65	0.96	0.86	26	-1
	Ponte_Verdi	485	0.31	0.71	0.43	0.74	41	-14
	Ragoli	504	0.19	0.27	0.95	0.67	11	0
	Gaiola	515	0.61	0.89	0.71	1.23	9	-5
	Lanzo	541	0.74	0.83	0.81	1.02	16	-4
	Ponte_Alto	1077	0.60	0.82	1.12	0.67	24	3
	Cassine	1364	-0.12	0.82	1.88	0.34	59	16
	Farigliano	1379	0.80	0.84	0.95	0.88	23	-2
	S_Secondo	1422	0.46	0.71	0.94	0.55	74	-2
	Palestro	2168	0.67	0.88	0.81	0.76	93	-15
	Tavagnasco	3096	0.59	0.90	0.61	0.94	64	-39
	Alba_Q_A	3180	0.75	0.81	1.12	0.90	45	8
	Carignano	3649	0.88	0.89	0.97	1.05	38	-2
	Torino_Murazzi	6134	0.73	0.88	1.24	1.03	61	19
	Casale_Monferrato	12882	0.55	0.83	1.33	0.75	156	60
	Spessa	35976	0.80	0.90	0.87	1.11	333	-99
	Cremona	47616	0.69	0.89	0.83	1.23	427	-171
	Pontelagoscuro	67487	0.69	0.88	0.91	1.28	565	-123
VALIDATION	Piana_Crixia	229	0.17	0.66	0.76	0.28	18	-1
	Ponte_dei_Tedeschi	361	0.15	0.41	0.41	0.82	14	-7
	Candoglia	1480	0.56	0.86	0.60	1.14	47	-29
	Piacenza	39195	0.76	0.89	0.83	1.13	384	-139
	Borgoforte	59169	0.68	0.88	0.85	1.26	521	-192
	min	171	-0.12	0.00	0.41	0.28	4	-192
	25%	436	0.25	0.71	0.81	0.74	15	-22
	median	1379	0.61	0.83	0.94	0.88	41	-2
	75%	4891	0.71	0.88	1.09	1.11	84	1
	max	67487	0.88	0.90	1.88	1.28	565	60
	mean	10781	0.51	0.75	0.98	0.89	114	-27

Table S3: Kling-Gupta Efficiency of the baseline simulation over 2017-2019 at the calibration and validation discharge stations and absolute differences for the corresponding simulations forced by satellite products.

	Station	Area [km²]	Baseline	SM2RAIN	GLEAM	C-SNOW	RT1	EO	SM2RAIN+GLEAM
CALIBRATION	Salsominore	171	0.06	-0.30	0.01	0.12	0.17	-0.02	-0.29
	Cartosio	180	0.69	-0.44	-0.02	0.03	0.05	-0.18	-0.50
	Valsigiara	192	0.20	-0.27	-0.01	0.10	0.41	0.16	-0.31
	Cimego	233	-0.03	0.01	0.01	-0.08	-0.03	-0.09	-0.12
	Ostia_Parmense	387	0.62	-0.13	-0.01	0.01	0.00	-0.10	-0.15
	Ponte_Verdi	485	0.31	-0.02	0.02	-0.01	-0.06	-0.13	-0.01
	Ragoli	504	0.19	-0.11	0.09	-0.07	-0.05	-0.22	-0.21
	Gaiola	515	0.61	-0.11	-0.01	0.07	-0.22	-0.09	-0.09
	Lanzo	541	0.74	-0.66	0.06	-0.01	-0.14	-0.36	-0.78
	Ponte_Alto	1077	0.60	-0.21	-0.18	0.05	0.04	-0.07	-0.42
	Cassine	1364	-0.12	-1.15	-0.03	0.07	0.28	-0.35	-1.30
	Farigliano	1379	0.80	-0.51	-0.03	-0.02	-0.12	-0.69	-0.52
	S_Secondo	1422	0.46	-0.02	-0.03	0.02	0.06	0.04	-0.08
	Palestro	2168	0.67	-0.20	-0.04	0.00	-0.03	-0.11	-0.32
	Tavagnasco	3096	0.59	0.29	0.09	0.11	-0.19	0.25	0.15
	Alba_Q_A	3180	0.75	-0.60	-0.04	0.01	-0.03	-0.56	-0.65
	Carignano	3649	0.88	-0.68	-0.01	0.00	-0.24	-0.34	-0.80
	Torino_Murazzi	6134	0.73	-1.04	-0.15	-0.10	0.02	-0.47	-1.30
	Casale_Monferrato	12882	0.55	-1.07	-0.23	-0.10	0.20	-0.67	-1.42
	Spessa	35976	0.80	-0.25	0.09	0.05	-0.20	-0.08	-0.39
	Cremona	47616	0.69	-0.10	0.16	0.06	-0.20	-0.03	-0.20
	Pontelagoscuro	67487	0.69	-0.11	0.15	0.04	-0.20	-0.06	-0.21
VALIDATION	Piana_Crixia	229	0.17	-0.25	0.00	0.00	0.00	0.04	-0.36
	Ponte_dei_Tedeschi	361	0.15	0.18	0.04	0.03	-0.04	0.19	0.21
	Candoglia	1480	0.56	0.19	0.06	0.08	-0.14	0.18	0.16
	Piacenza	39195	0.76	-0.15	0.11	0.04	-0.19	-0.02	-0.28
	Borgoforte	59169	0.68	-0.07	0.17	0.05	-0.19	-0.02	-0.16
	Mean KGE		0.51	0.22	0.52	0.53	0.47	0.37	0.13
	Δ(Mean KGE)			-0.29	0.01	0.02	-0.04	-0.14	-0.38
	std (ΔKGE)			0.37	0.09	0.06	0.16	0.25	0.43

Table S4: Summary of ground and satellite-based dynamic input used in the hydrological model runs.

		Baseline	SM2RAIN	GLEAM	C-SNOW	RT1	EO	SM2RAIN +GLEAM
GROUND BASED	MCM radar+gauges precipitation	X		X	X	X		
	Interpolated point observations	X	X	X*	X	X	X*	X*
SATELLITE PRODUCTS	SM2RAIN precipitation		X				X	X
	GLEAM evaporation			X			X	X
	C-SNOW snow depth (assimilation)				X		X	
	RT1 soil moisture (assimilation)					X	X	

* only air temperature, relative humidity and solar radiation