*Supplement of*

# High resolution satellite products improve hydrological modeling in northern Italy

**Lorenzo Alfieri et al.**

*Correspondence to*: Lorenzo Alfieri (Lorenzo.Alfieri@cimafoundation.org)

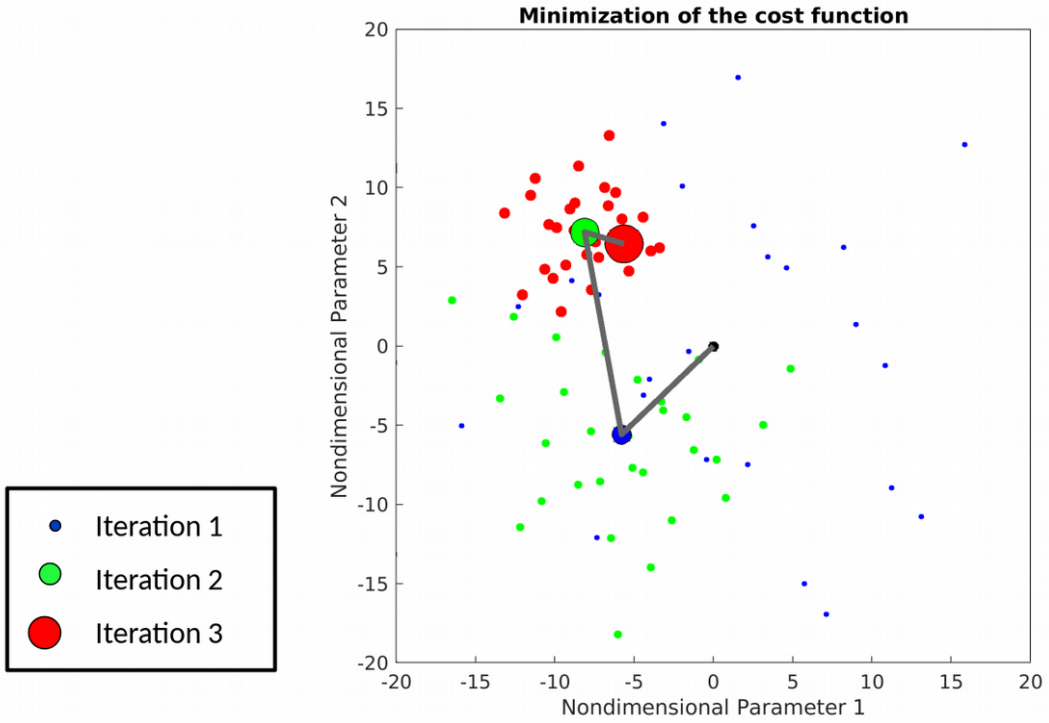


**Figure S1***:* Representation of the calibration search algorithm (in a 2-dimension space). The optimal value of each gaussian exploration is used as the centre of the next one.

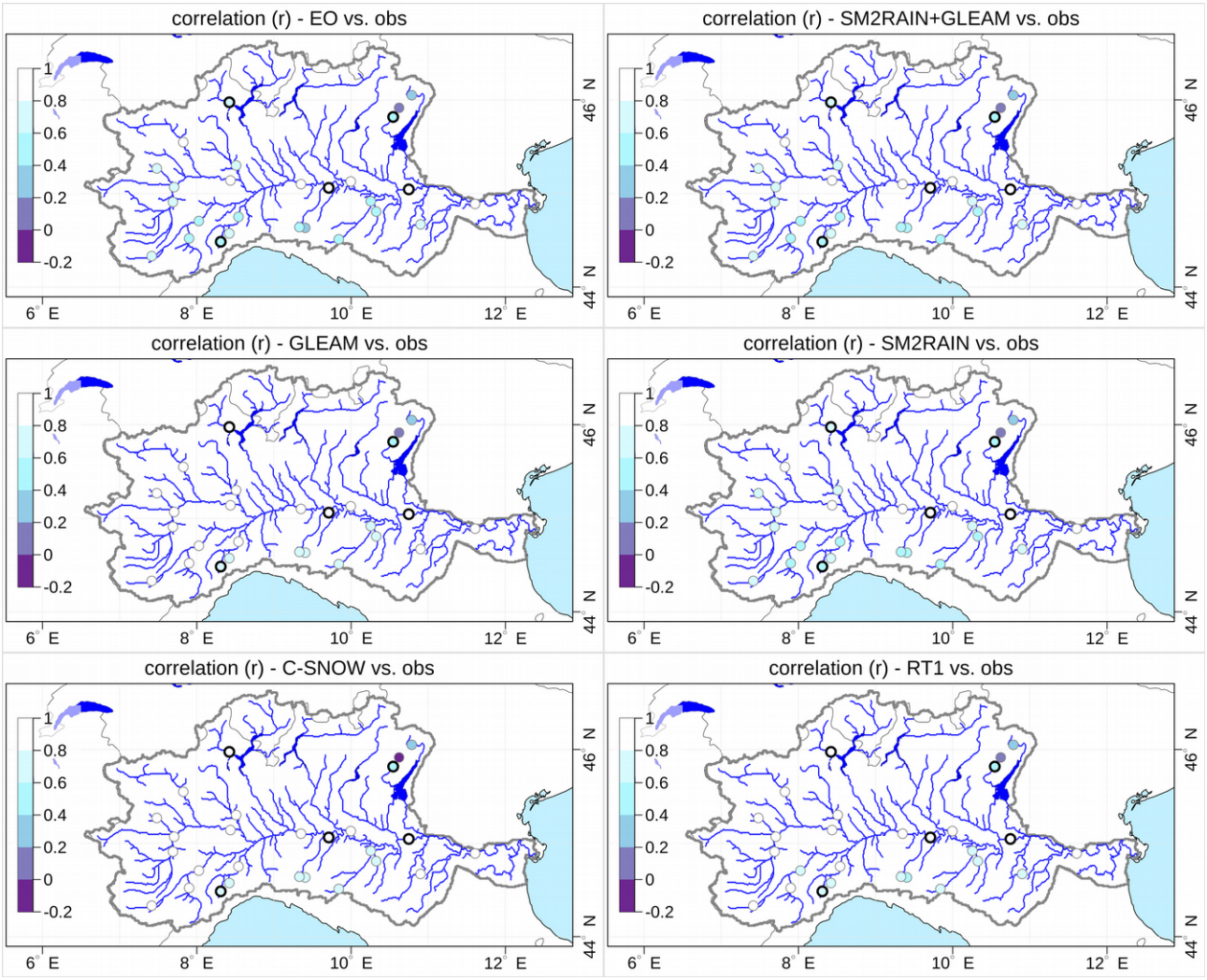


**Figure S2***:* Spatial distribution of the Pearson's correlation (r) of the six model runs driven by the four input satellite products versus observed discharges at the measurement stations. Validation stations are marked with a bold circle. Multi-product experiments are in the first row, while single-product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

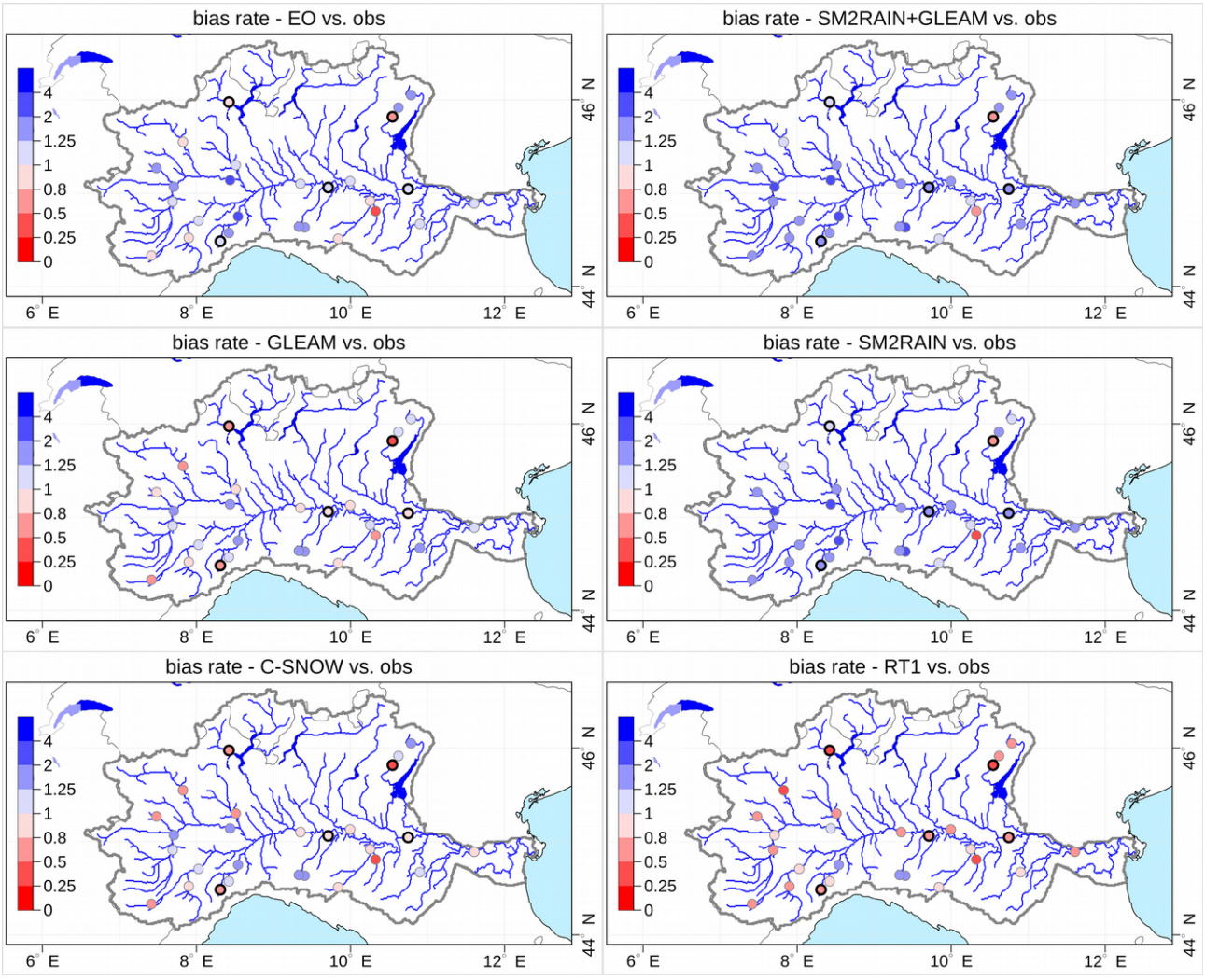


**Figure S3***:* Like Figure S2 for the bias rate at the measurement stations.

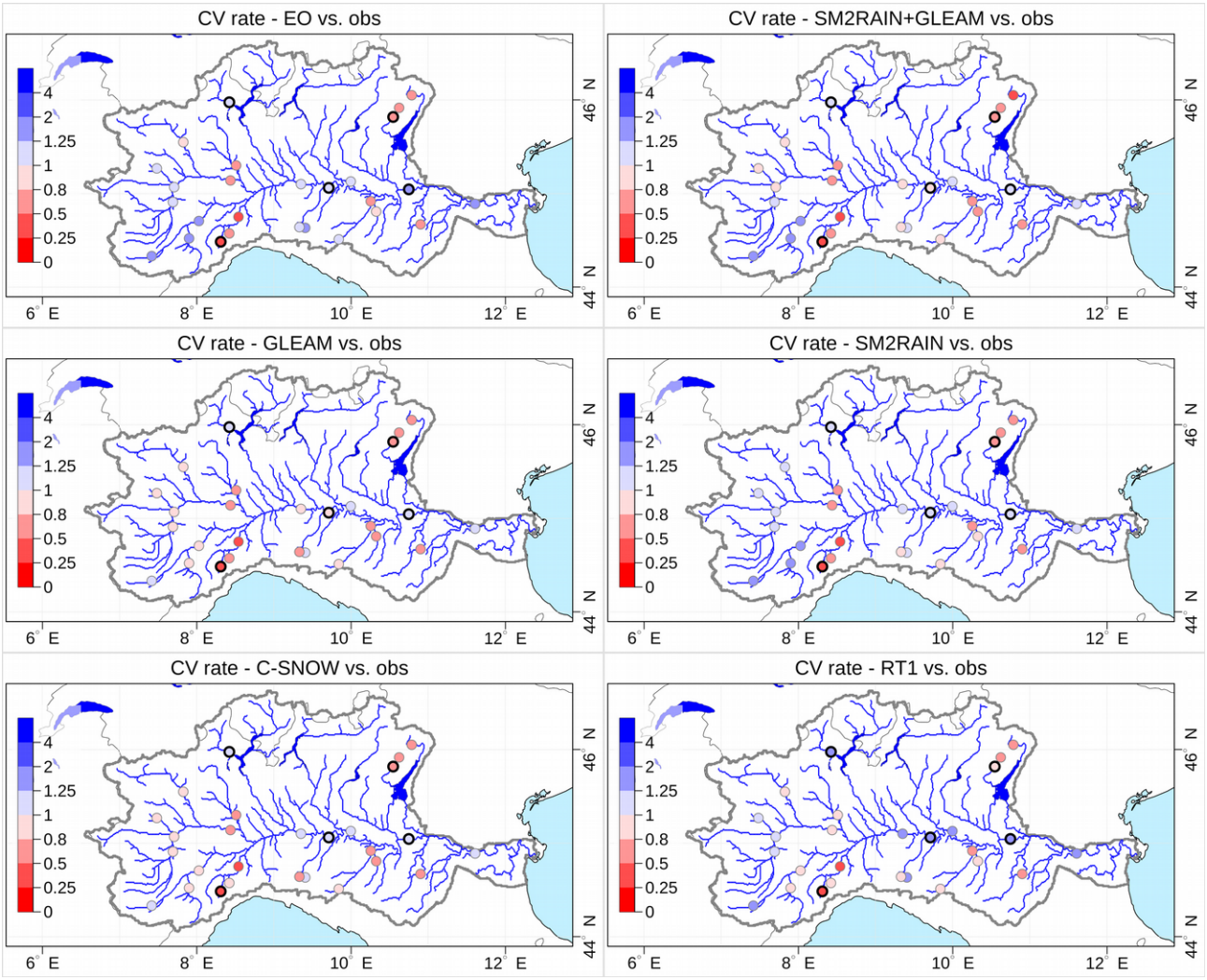


**Figure S4***:* Like Figure S2 for the the Coefficient of Variation rate (CV rate) at the measurement stations.

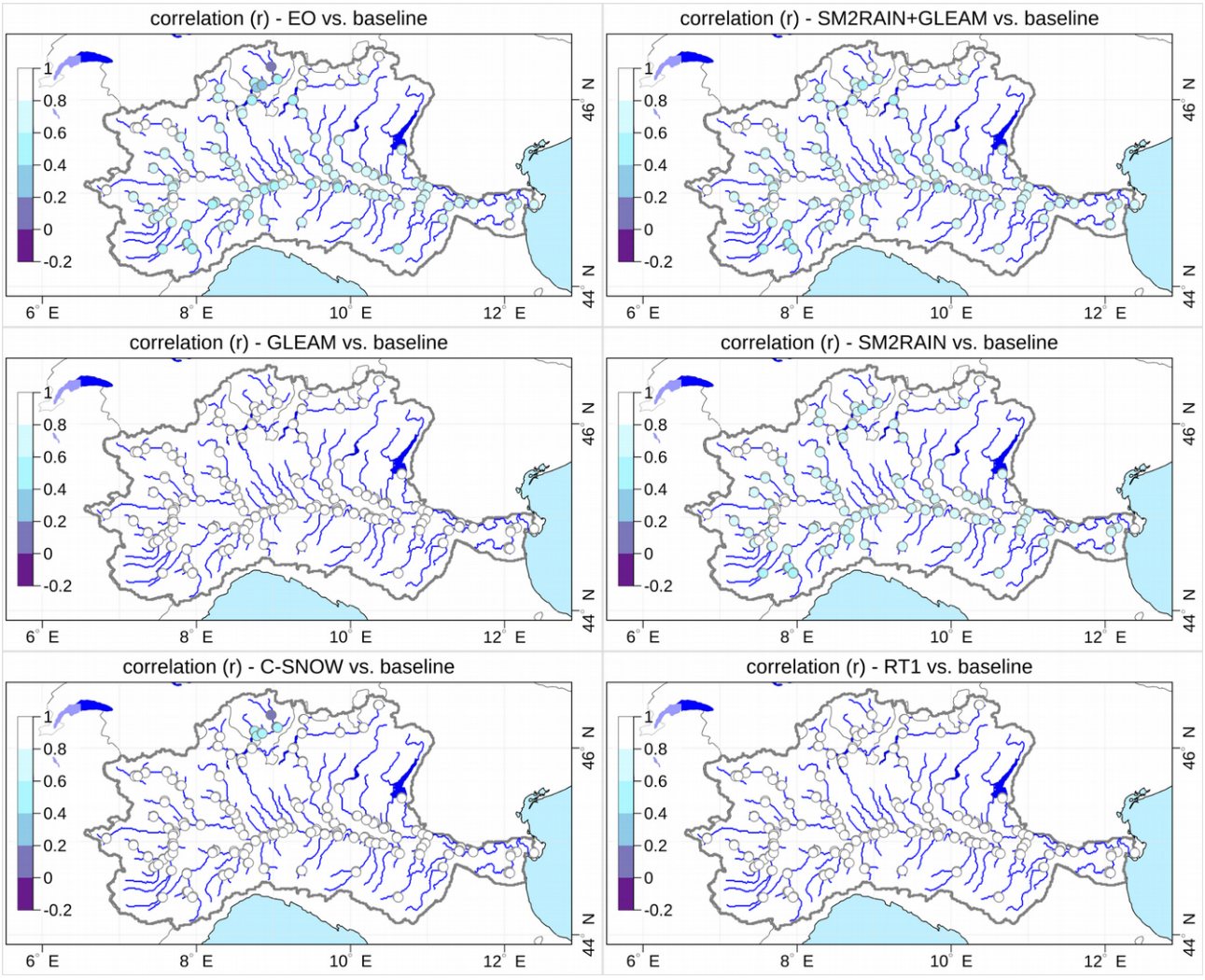


**Figure S5***:* Spatial distribution of the correlation (r) of the six model runs driven by the four input satellite products versus the baseline simulation at each modeled river reach. Multi-product experiments are in the first row, while single-product experiments in row 2 (forcing input) and 3 (data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

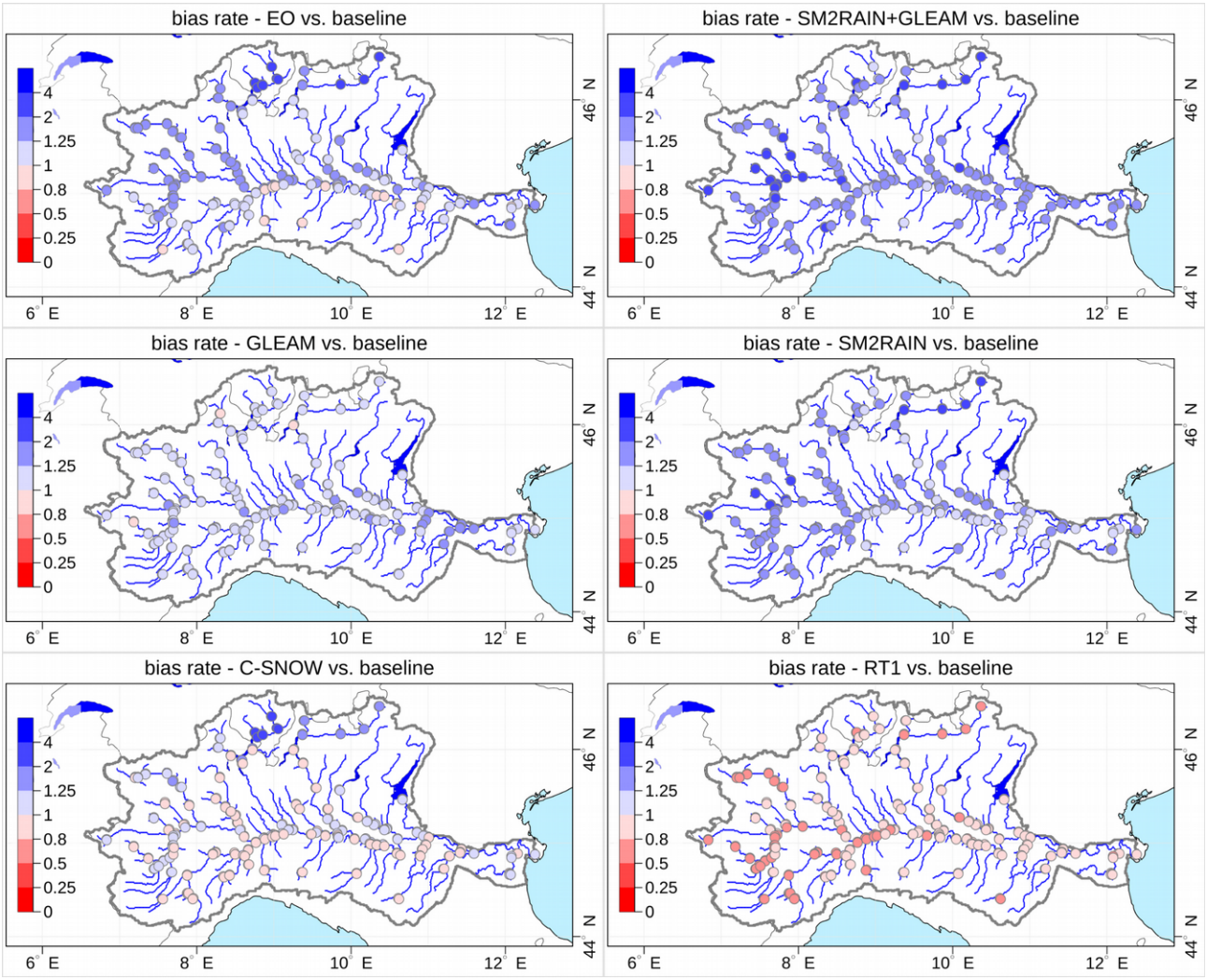


**Figure S6***:* Like Figure S5 for the bias rate at each modeled river reach.

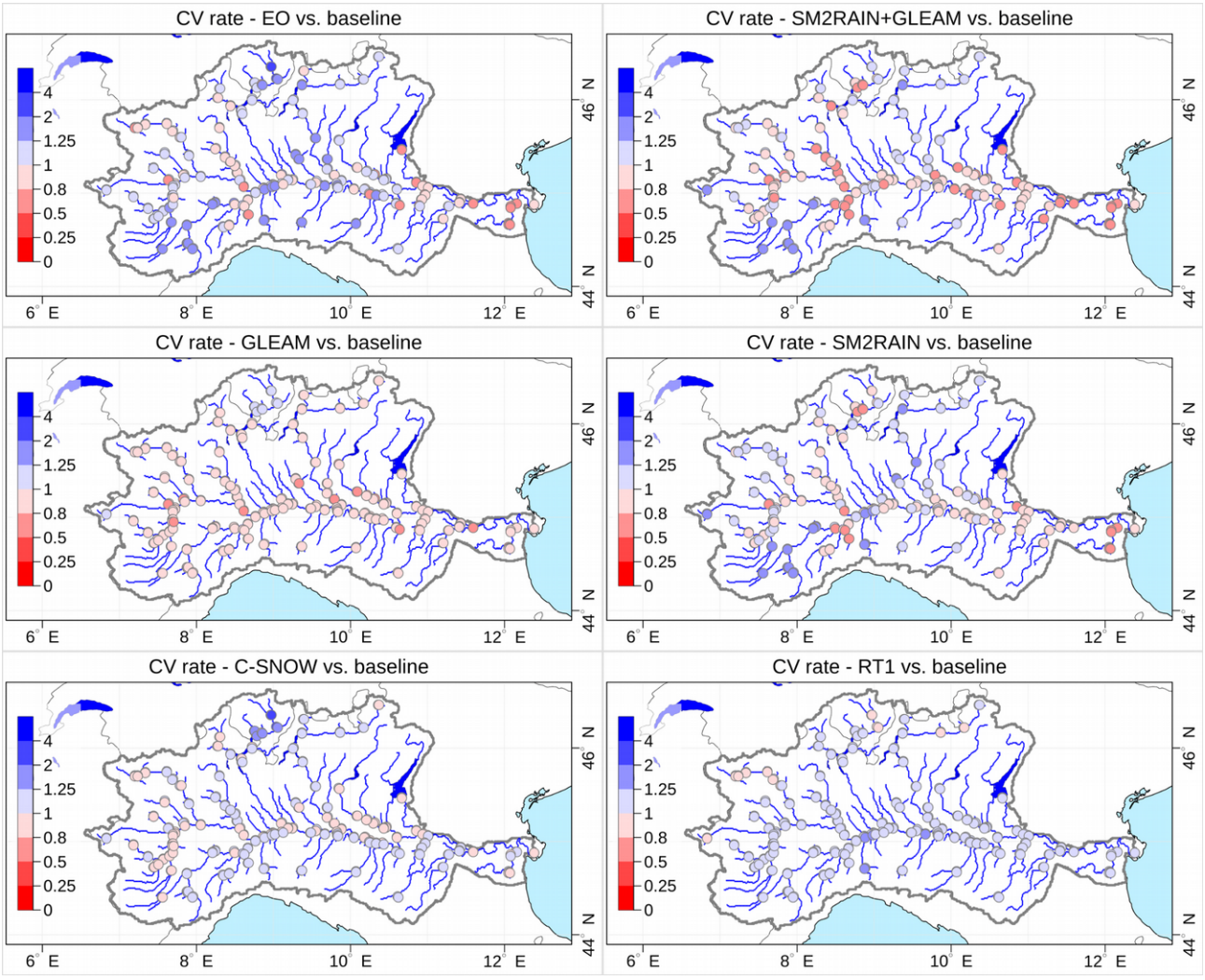


**Figure S7***:* Like Figure S5 for the coefficient of variation rate (CV rate) at each modeled river reach.

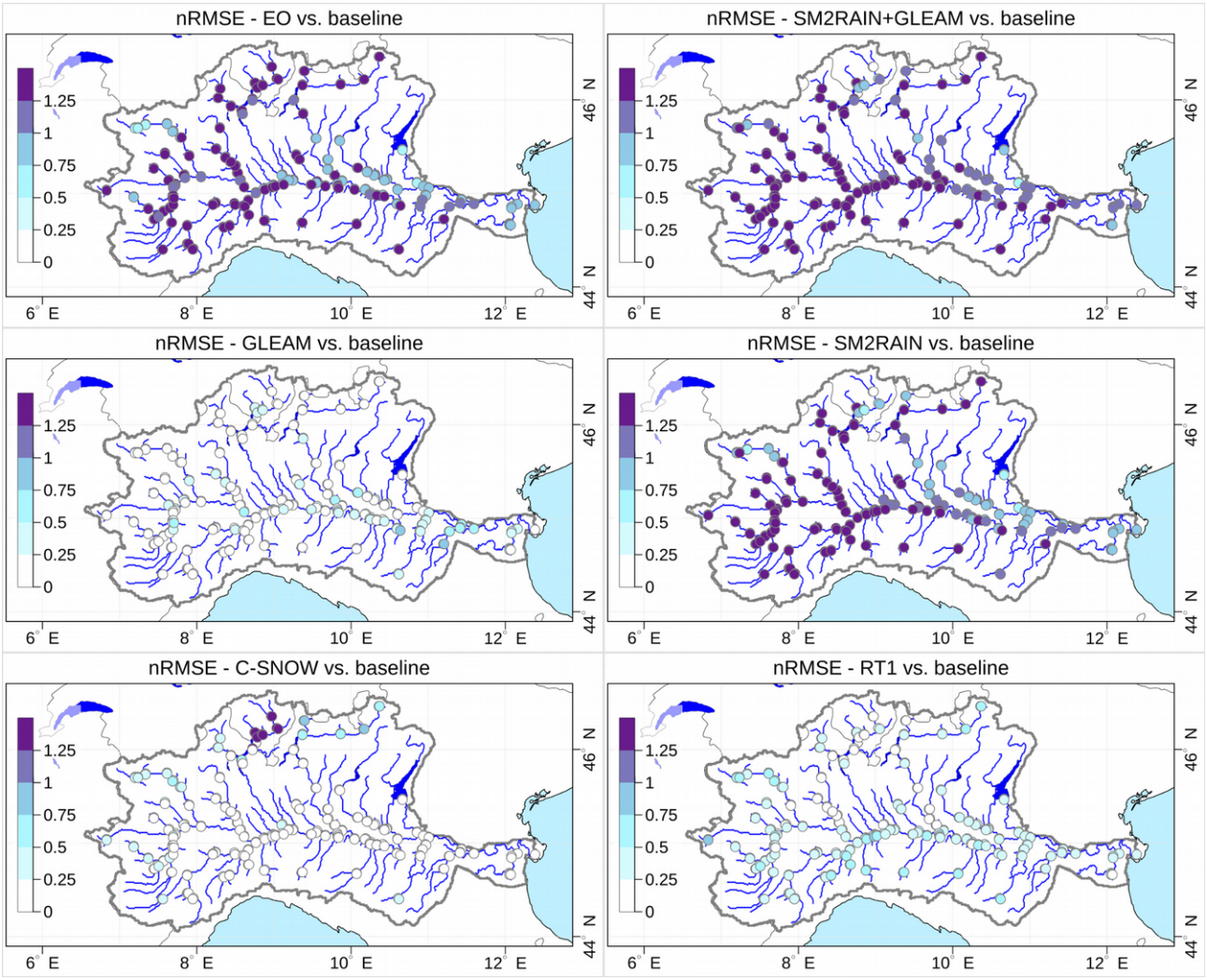


**Figure S8***:* Like Figure S5 for the normalized root mean square error (nRMSE) at each modeled river reach.

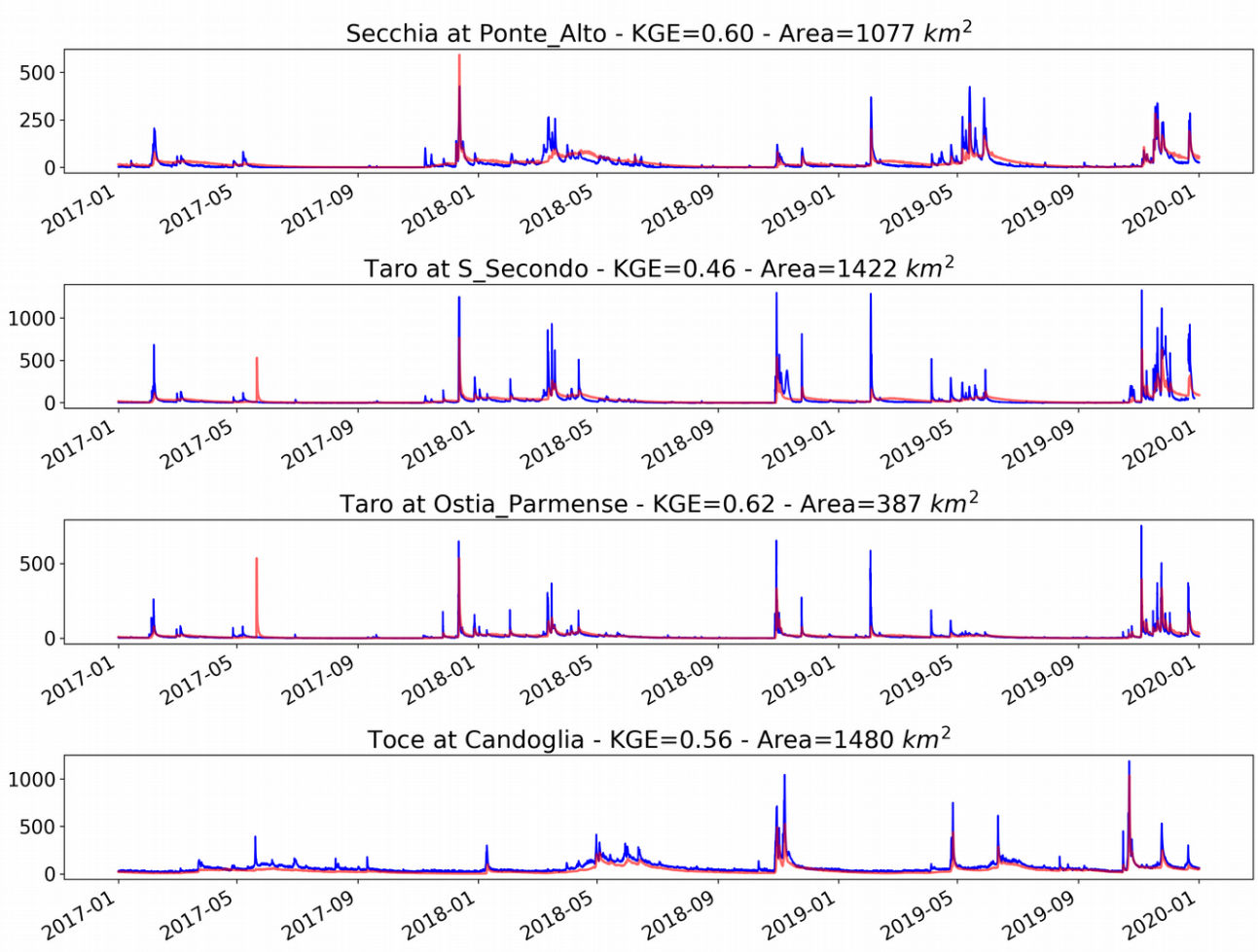


**Figure S9***:* Observed versus simulated (baseline) discharge [$m^3/s$] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

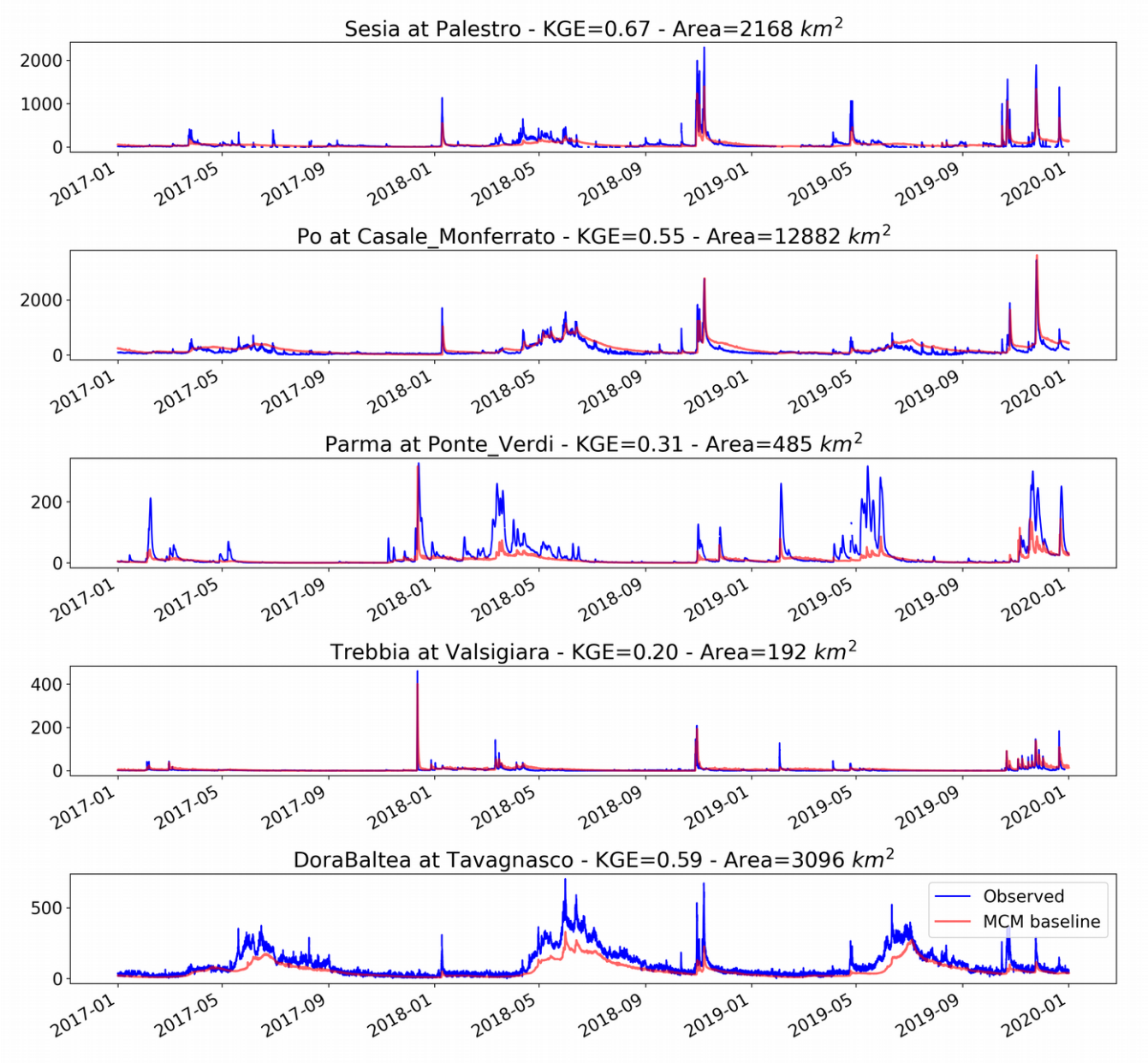


**Figure S9** (continued)*:* Observed versus simulated (baseline) discharge [$m^3/s$] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

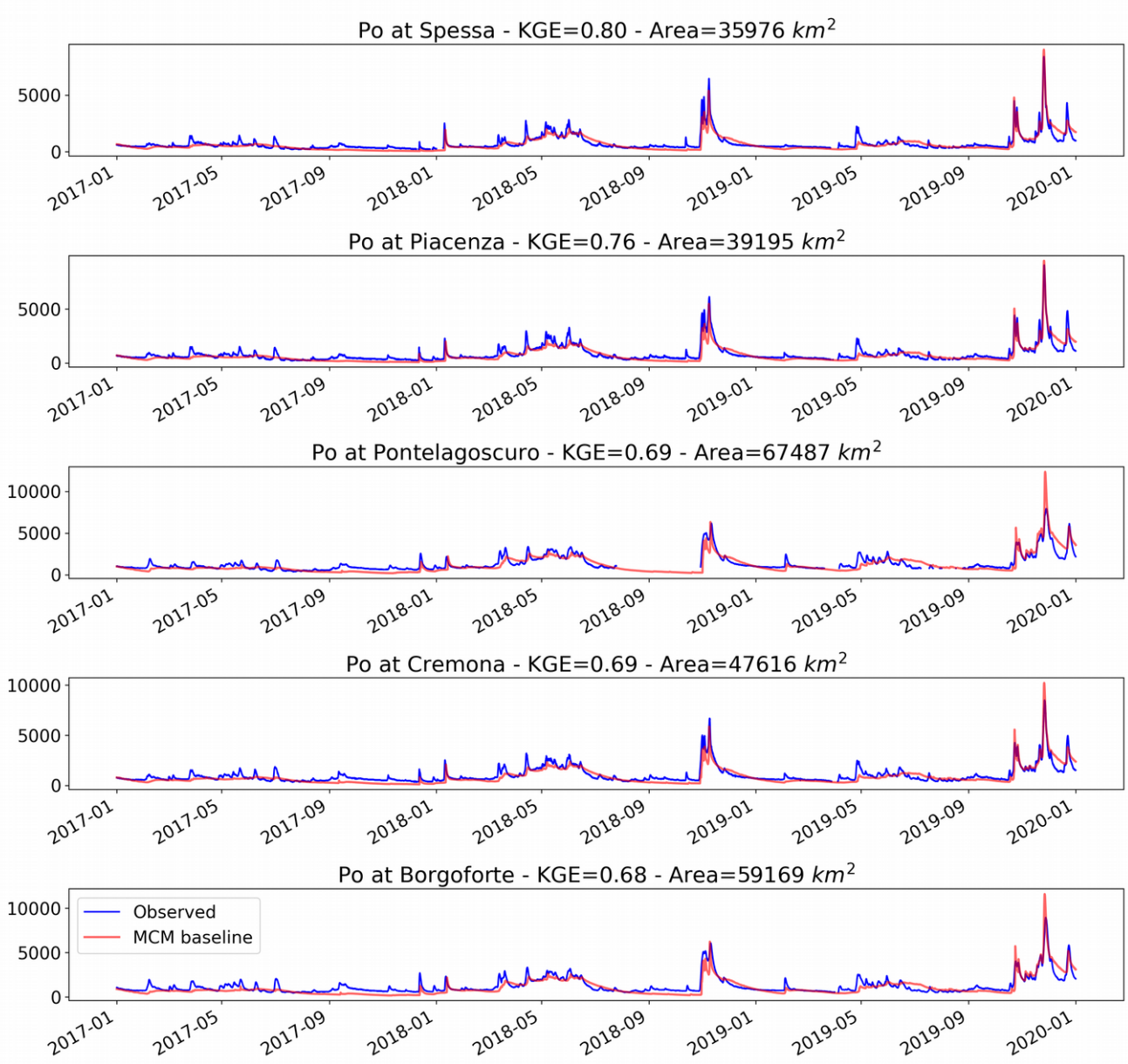


**Figure S9** (continued)*:* Observed versus simulated (baseline) discharge [$m^3/s$] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

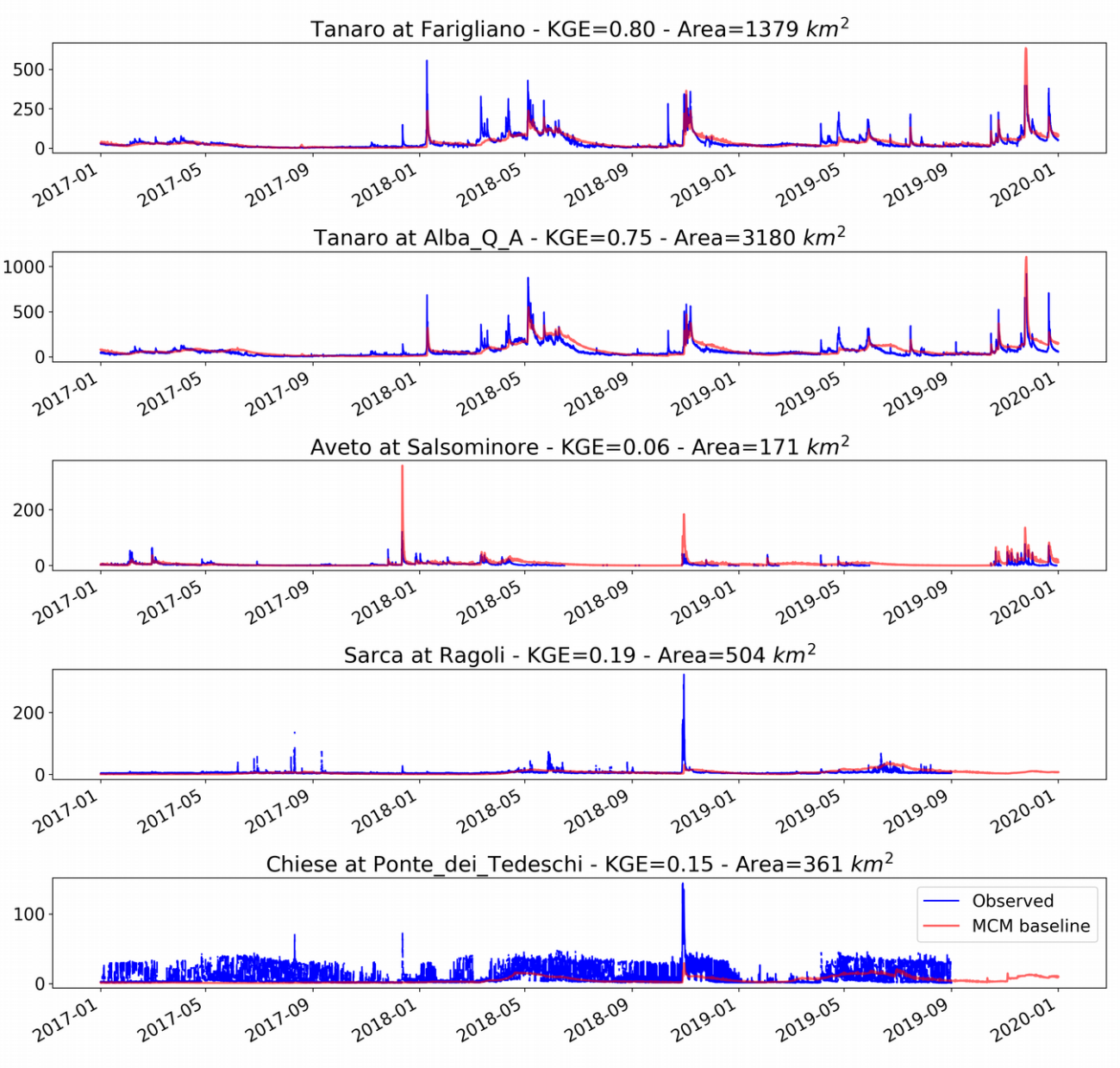


**Figure S9** (continued)*:* Observed versus simulated (baseline) discharge [$m^3/s$] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

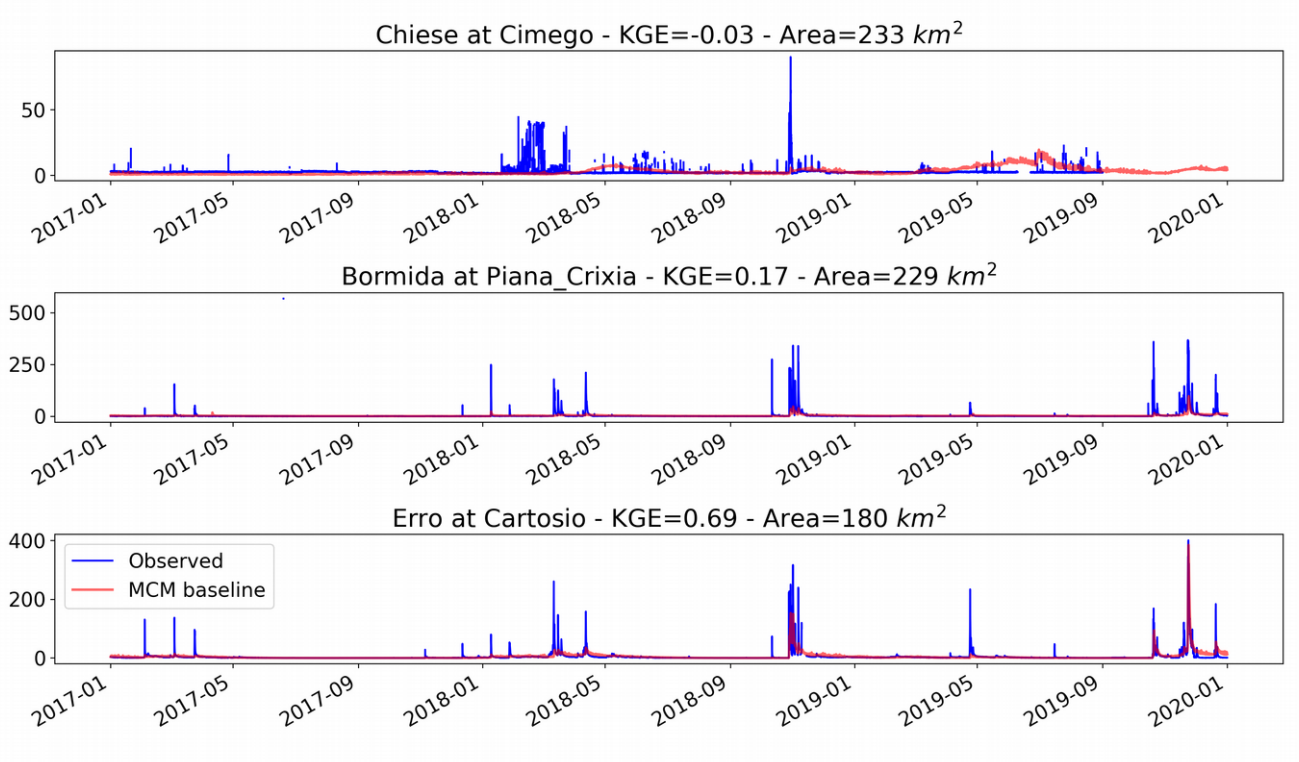


**Figure S9** (continued)*:* Observed versus simulated (baseline) discharge [$m^3/s$] for the years 2017-2019 at the 22 river gauging stations not shown in Figure 7 of the article.

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 |

80

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