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Anthropogenic influence on the Rhine water temperatures

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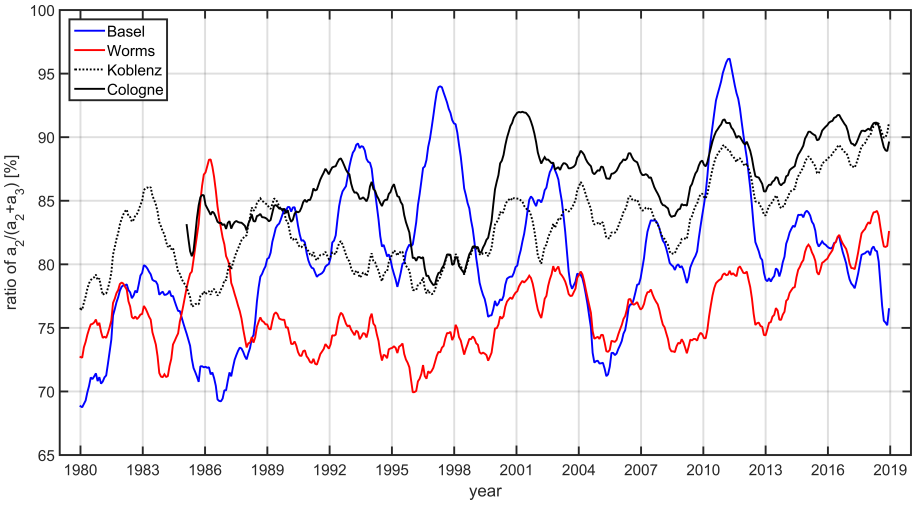

Figure S1. The relative contribution of a_2 to the variation in T_w at the four monitoring stations.

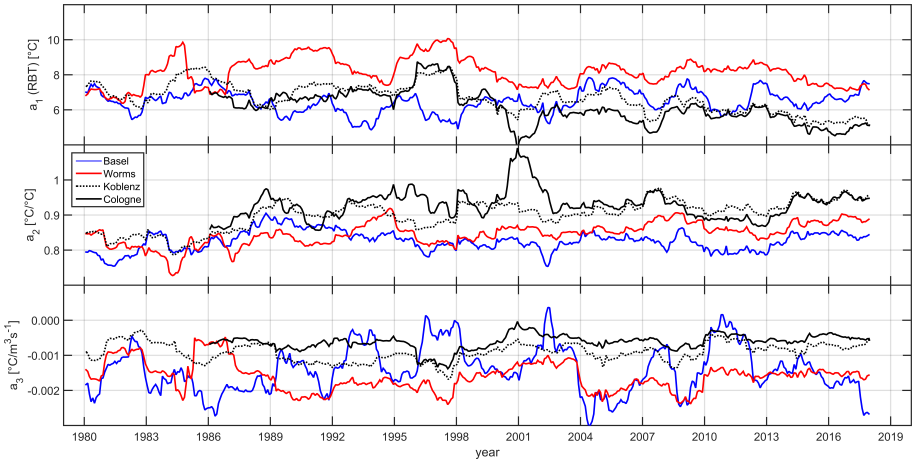

Figure S2. Evolution of a_1, a_2 and a_3 at the four monitoring stations. The regression window is 2 years and is moved by 1 month each step.

1 Supplemental material

1.1 Regression coefficients

In Sec. 3.2 coefficients a_{1-3} are calculated by regressing T_w by T_c and Q. The regression is done on a two-year window with a step size of one month. Fig. S1 shows the evolution of the regression coefficients at all four monitoring stations for the Time-lag+weight scenario, as an example. Fig. S2 shows a_2 (meteorology) in relation to both environmental influences $a_2 + a3$. The y-axis percentage gives an indication, how much influence a_2 has on the variations of T_w. The remaining percentage to 100 % can be attributed to a_3 (hydrology).

	Basel					Worms				
year	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
2000	1.63	1.45	1.45	2.36	2.70	1.13	1.14	1.13	2.24	2.47
2001	1.61	1.56	1.61	2.39	2.51	0.98	1.13	1.26	2.34	2.43
2002	2.08	1.81	1.76	2.69	2.84	1.25	1.27	1.41	2.53	2.56
2003	1.84	1.75	1.86	2.82	3.04	1.05	1.19	1.48	2.48	2.56
2004	1.52	1.42	1.50	2.40	2.74	1.08	1.09	1.18	2.48	2.65
2005	1.80	1.69	1.77	2.57	2.78	1.11	1.37	1.66	2.44	2.54
2006	1.41	1.43	1.57	2.50	2.42	1.10	1.23	1.45	2.50	2.39
2007	1.72	1.56	1.61	2.57	2.68	1.00	1.17	1.36	2.44	2.51
2008	1.66	1.55	1.61	2.52	2.66	1.06	1.10	1.24	2.50	2.57
2009	1.67	1.62	1.69	2.61	2.85	1.13	1.20	1.25	2.50	2.62
2010	1.83	1.72	1.81	2.67	2.71	1.17	1.37	1.58	2.54	2.52
2011	1.81	1.72	1.79	2.74	2.88	1.02	1.43	1.74	2.26	2.37
2012	1.90	1.70	1.69	2.74	3.11	1.12	1.12	1.34	2.73	2.99
2013	1.55	1.61	1.70	2.54	2.77	1.11	1.34	1.51	2.37	2.52
2014	1.60	1.57	1.65	2.46	2.65	0.89	1.02	1.14	2.13	2.23
2015	1.60	1.60	1.70	2.54	2.71	1.08	1.18	1.31	2.44	2.51
2016	1.51	1.54	1.64	2.56	2.60	0.92	1.04	1.11	2.46	2.49
2017	1.79	1.75	1.81	2.77	2.75	1.19	1.26	1.35	2.67	2.63
2018	1.74	1.80	1.93	2.66	2.94	1.22	1.32	1.42	2.47	2.55

Table S1. Root mean square errors [^oC] for five calculation methods. The model, using the coefficients of the 2001 regression, is applied to the years 2000-2018. The first row is the scenarios used for all other results.

1.2 2000-2018

We randomly chose the year 2001 as a reference learning year and regressed T_w vs T_c and Q. The coefficients obtained from this regression were used to model T_w for all the other years. Tab. S, S, Sand S show the RMSE and NCS data for all calculation methods and measurement stations.

1.3 RMSE and NSC at different flwo speeds

We present the RMSE and NSC calcualtions for all four Stations, for all calculation methods of T_c, over the whole data-set at flow-speeds from 0.3 ms^{-1} to 1.4 ms^{-1}, Tab. S, S, S and S.

	Koblenz					Cologne				
year	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
2000	0.87	1.18	1.44	2.21	2.52	1.46	2.06	2.27	3.11	3.04
2001	0.75	1.26	1.55	2.32	2.55	1.66	2.09	2.28	2.95	2.83
2002	1.15	1.53	1.84	2.51	2.70	1.56	1.89	2.02	2.98	3.01
2003	0.95	1.65	2.09	2.39	2.78	1.25	1.66	1.81	2.71	2.77
2004	1.06	1.60	1.94	2.38	2.63	1.59	1.76	1.81	2.82	2.80
2005	1.07	1.76	2.15	2.47	2.75	1.56	1.98	2.12	3.09	2.88
2006	1.05	1.65	2.05	2.42	2.55	1.33	1.63	1.77	2.82	2.92
2007	0.91	1.32	1.63	2.48	2.66	1.43	1.64	1.80	2.87	3.08
2008	0.97	1.38	1.68	2.48	2.65	1.88	2.25	2.41	3.05	3.08
2009	1.04	1.33	1.52	2.51	2.69	1.46	1.61	1.60	2.67	2.74
2010	1.01	1.56	1.90	2.54	2.68	1.65	1.97	2.04	3.09	2.85
2011	0.93	1.51	1.87	2.44	2.65	1.61	1.98	1.99	3.01	2.88
2012	0.94	1.29	1.62	2.60	2.87	1.43	1.52	1.60	2.70	3.12
2013	1.22	1.61	1.86	2.53	2.77	1.55	2.07	2.16	3.13	2.98
2014	1.10	1.32	1.43	2.34	2.55	1.52	1.61	1.55	2.58	2.74
2015	1.09	1.39	1.57	2.55	2.84	1.88	2.01	2.02	2.84	2.85
2016	0.88	1.21	1.34	2.52	2.62	1.68	1.82	1.84	2.62	2.88
2017	1.04	1.39	1.69	2.67	2.83	1.58	1.63	1.56	3.10	3.12
2018	0.97	1.60	1.88	2.34	2.61	1.64	1.78	1.84	2.65	2.98

Table S2. Root mean square errors [^oC] for five calculation methods. The model, using the coefficients of the 2001 regression, is applied to the years 2000-2018. The first row is the scenarios used for all other results.

	Basel					Worms				
year	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
2000	0.93	0.91	0.93	0.80	0.74	0.96	0.96	0.96	0.83	0.79
2001	0.92	0.92	0.91	0.81	0.79	0.96	0.97	0.96	0.85	0.83
2002	0.89	0.85	0.89	0.75	0.73	0.95	0.95	0.94	0.80	0.79
2003	0.94	0.93	0.93	0.84	0.81	0.97	0.98	0.96	0.88	0.87
2004	0.94	0.93	0.93	0.82	0.77	0.97	0.97	0.96	0.83	0.80
2005	0.92	0.91	0.91	0.81	0.78	0.95	0.97	0.93	0.84	0.83
2006	0.95	0.95	0.94	0.84	0.86	0.96	0.97	0.95	0.85	0.87
2007	0.90	0.88	0.90	0.74	0.72	0.95	0.96	0.93	0.78	0.77
2008	0.92	0.91	0.92	0.80	0.78	0.96	0.97	0.96	0.82	0.81
2009	0.93	0.93	0.93	0.82	0.79	0.97	0.97	0.96	0.85	0.84
2010	0.91	0.90	0.90	0.79	0.78	0.95	0.97	0.94	0.84	0.84
2011	0.91	0.91	0.91	0.78	0.76	0.94	0.97	0.92	0.86	0.84
2012	0.92	0.90	0.92	0.79	0.73	0.97	0.97	0.95	0.81	0.77
2013	0.93	0.93	0.92	0.82	0.79	0.95	0.97	0.94	0.85	0.83
2014	0.90	0.90	0.89	0.76	0.72	0.96	0.97	0.95	0.82	0.80
2015	0.93	0.93	0.92	0.82	0.80	0.96	0.97	0.95	0.84	0.83
2016	0.93	0.93	0.92	0.79	0.79	0.97	0.98	0.96	0.82	0.82
2017	0.92	0.92	0.92	0.81	0.81	0.96	0.97	0.96	0.84	0.84
2018	0.93	0.94	0.92	0.85	0.81	0.97	0.97	0.96	0.88	0.87

Table S3. NSC for five calculation methods. The model, using the coefficients of the 2001 regression, is applied to the years 2000-2018. The first row is the scenarios used for all other results.

	Koblenz					Cologne				
year	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
2000	0.98	0.96	0.94	0.85	0.81	0.95	0.90	0.88	0.78	0.79
2001	0.99	0.96	0.94	0.86	0.83	0.94	0.91	0.90	0.82	0.84
2002	0.96	0.94	0.91	0.83	0.80	0.92	0.89	0.87	0.71	0.71
2003	0.98	0.95	0.92	0.89	0.85	0.96	0.93	0.91	0.81	0.80
2004	0.97	0.93	0.90	0.85	0.82	0.94	0.93	0.92	0.82	0.82
2005	0.97	0.93	0.89	0.86	0.83	0.95	0.91	0.90	0.79	0.82
2006	0.98	0.94	0.91	0.88	0.87	0.95	0.92	0.91	0.77	0.75
2007	0.97	0.95	0.92	0.81	0.78	0.95	0.93	0.92	0.79	0.76
2008	0.98	0.95	0.93	0.84	0.82	0.91	0.87	0.85	0.76	0.76
2009	0.98	0.96	0.95	0.86	0.84	0.93	0.91	0.92	0.76	0.75
2010	0.98	0.95	0.92	0.86	0.84	0.93	0.90	0.89	0.75	0.79
2011	0.98	0.94	0.91	0.85	0.82	0.93	0.90	0.89	0.76	0.78
2012	0.98	0.96	0.94	0.84	0.81	0.96	0.95	0.94	0.84	0.79
2013	0.96	0.94	0.92	0.84	0.81	0.95	0.92	0.91	0.81	0.82
2014	0.96	0.94	0.93	0.82	0.79	0.92	0.91	0.92	0.78	0.75
2015	0.97	0.95	0.94	0.84	0.80	0.91	0.89	0.89	0.79	0.79
2016	0.98	0.96	0.95	0.83	0.82	0.93	0.91	0.91	0.82	0.78
2017	0.98	0.96	0.94	0.85	0.83	0.95	0.94	0.95	0.79	0.79
2018	0.98	0.95	0.93	0.89	0.87	0.95	0.94	0.93	0.86	0.83

Table S4. NSC for five calculation methods. The model, using the coefficients of the 2001 regression, is applied to the years 2000-2018. The first row is the scenarios used for all other results.

	Basel					Worms				
flow speed	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
0.30 ms^{-1}	1.49	1.47	1.57	2.48	2.67	1.15	1.40	1.60	2.43	2.55
0.40 ms^{-1}	1.65	1.56	1.62	2.48	2.67	1.24	1.33	1.45	2.43	2.55
0.50 ms^{-1}	1.76	1.62	1.66	2.48	2.67	1.35	1.35	1.39	2.43	2.55
0.60 ms^{-1}	1.85	1.68	1.70	2.48	2.67	1.43	1.37	1.37	2.43	2.55
0.70 ms^{-1}	1.92	1.73	1.74	2.48	2.67	1.51	1.41	1.37	2.43	2.55
0.80 ms^{-1}	1.98	1.77	1.77	2.48	2.67	1.60	1.48	1.39	2.43	2.55
0.90 ms^{-1}	2.04	1.82	1.80	2.48	2.67	1.66	1.53	1.41	2.43	2.55
1.00 ms^{-1}	2.07	1.84	1.82	2.48	2.67	1.72	1.58	1.45	2.43	2.55
1.10 ms^{-1}	2.12	1.89	1.85	2.48	2.67	1.78	1.64	1.48	2.43	2.55
1.20 ms^{-1}	2.14	1.90	1.87	2.48	2.67	1.81	1.65	1.52	2.43	2.55
1.30 ms^{-1}	2.19	1.96	1.90	2.48	2.67	1.87	1.71	1.56	2.43	2.55
1.40 ms^{-1}	2.20	1.97	1.92	2.48	2.67	1.89	1.72	1.59	2.43	2.55

Table S5. RMSE calculation for twelve different flow-speeds and five calculation methods at Basel and Worms. The calculation is done with the whole data-set.

	Koblenz					Cologne				
flow speed	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
0.30 ms^{-1}	1.03	1.64	1.98	2.37	2.63	1.35	2.12	2.41	2.97	2.85
0.40 ms^{-1}	1.02	1.43	1.70	2.37	2.63	1.31	1.88	2.08	2.97	2.85
0.50 ms^{-1}	1.08	1.33	1.54	2.37	2.63	1.35	1.75	1.89	2.97	2.85
0.60 ms^{-1}	1.15	1.28	1.44	2.37	2.63	1.41	1.68	1.78	2.97	2.85
0.70 ms^{-1}	1.24	1.28	1.38	2.37	2.63	1.48	1.64	1.71	2.97	2.85
0.80 ms^{-1}	1.32	1.29	1.34	2.37	2.63	1.55	1.63	1.67	2.97	2.85
0.90 ms^{-1}	1.39	1.31	1.33	2.37	2.63	1.60	1.63	1.65	2.97	2.85
1.00 ms^{-1}	1.45	1.34	1.33	2.37	2.63	1.68	1.66	1.64	2.97	2.85
1.10 ms^{-1}	1.51	1.38	1.35	2.37	2.63	1.73	1.68	1.64	2.97	2.85
1.20 ms^{-1}	1.58	1.43	1.37	2.37	2.63	1.79	1.71	1.65	2.97	2.85
1.30 ms^{-1}	1.64	1.49	1.39	2.37	2.63	1.82	1.72	1.67	2.97	2.85
1.40 ms^{-1}	1.66	1.50	1.42	2.37	2.63	1.87	1.76	1.69	2.97	2.85

Table S6. RMSE calculation for twelve different flow-speeds and five calculation methods at Koblenz and Cologne. The calculation is done with the whole data-set.

	Basel					Worms				
flow speed	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
0.30 ms^{-1}	0.94	0.94	0.93	0.82	0.79	0.96	0.95	0.93	0.84	0.82
0.40 ms^{-1}	0.92	0.93	0.92	0.82	0.79	0.96	0.95	0.94	0.84	0.82
0.50 ms^{-1}	0.91	0.92	0.92	0.82	0.79	0.95	0.95	0.95	0.84	0.82
0.60 ms^{-1}	0.90	0.92	0.92	0.82	0.79	0.94	0.95	0.95	0.84	0.82
0.70 ms^{-1}	0.89	0.91	0.91	0.82	0.79	0.94	0.94	0.95	0.84	0.82
0.80 ms^{-1}	0.89	0.91	0.91	0.82	0.79	0.93	0.94	0.95	0.84	0.82
0.90 ms^{-1}	0.88	0.90	0.91	0.82	0.79	0.92	0.94	0.94	0.84	0.82
1.00 ms^{-1}	0.88	0.90	0.90	0.82	0.79	0.92	0.93	0.94	0.84	0.82
1.10 ms^{-1}	0.87	0.90	0.90	0.82	0.79	0.91	0.93	0.94	0.84	0.82
1.20 ms^{-1}	0.87	0.89	0.90	0.82	0.79	0.91	0.93	0.94	0.84	0.82
1.30 ms^{-1}	0.86	0.89	0.89	0.82	0.79	0.90	0.92	0.93	0.84	0.82
1.40 ms^{-1}	0.86	0.89	0.89	0.82	0.79	0.90	0.92	0.93	0.84	0.82

Table S7. NSC calculation for twelve different flow-speeds and five calculation methods at Koblenz and Cologne. The calculation is done with the whole data-set.

	Koblenz					Cologne				
flow speed	ACC*w+Δt	w+Δt	avg+Δt	avg	point	ACC*w+Δt	w+Δt	avg+Δt	avg	point
0.30 ms^{-1}	0.97	0.93	0.90	0.86	0.82	0.96	0.89	0.86	0.79	0.81
0.40 ms^{-1}	0.97	0.95	0.93	0.86	0.82	0.96	0.92	0.90	0.79	0.81
0.50 ms^{-1}	0.97	0.95	0.94	0.86	0.82	0.96	0.93	0.91	0.79	0.81
0.60 ms^{-1}	0.97	0.96	0.95	0.86	0.82	0.95	0.93	0.92	0.79	0.81
0.70 ms^{-1}	0.96	0.96	0.95	0.86	0.82	0.95	0.94	0.93	0.79	0.81
0.80 ms^{-1}	0.96	0.96	0.95	0.86	0.82	0.94	0.94	0.93	0.79	0.81
0.90 ms^{-1}	0.95	0.96	0.95	0.86	0.82	0.94	0.94	0.93	0.79	0.81
1.00 ms^{-1}	0.95	0.95	0.95	0.86	0.82	0.93	0.93	0.94	0.79	0.81
1.10 ms^{-1}	0.94	0.95	0.95	0.86	0.82	0.93	0.93	0.94	0.79	0.81
1.20 ms^{-1}	0.94	0.95	0.95	0.86	0.82	0.92	0.93	0.93	0.79	0.81
1.30 ms^{-1}	0.93	0.94	0.95	0.86	0.82	0.92	0.93	0.93	0.79	0.81
1.40 ms^{-1}	0.93	0.94	0.95	0.86	0.82	0.92	0.93	0.93	0.79	0.81

Table S8. NSC calculation for twelve different flow-speeds and five calculation methods at Koblenz and Cologne. The calculation is done with the whole data-set.