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Discussions

Interactive comment on "Anthropogenic Influence on the Rhine water temperatures" *by* Alex Zavarsky and Lars Duester

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General comments

In this study, the authors analyze the effects of Nuclear Power Plants on river water temperature of the Rhine. The authors propose a multiple linear regression model where river water temperature is simulated based on air temperature and streamflow as predictor variables. Air temperature is evaluated through an averaging procedure that accounts for the geomorphology of the hydrological catchment. The intercept of the multiple linear regression model is used as a proxy for the anthropogenic impact on river water temperature and is compared to the time series of GDP and heat input from NPPs.

The presentation of the methodological approach and of the results should be improved, both in terms of clarity and quality. In my opinion the robustness of some

methodological aspects is weak (e.g., the use of a constant flow velocity, the interpretation of the multiple linear regression intercept as "indicator for industrial heat input") and the discussion of the results should be expanded and deepened. The literature review on modeling of river water temperature and assessment of anthropogenic impacts should be updated and the grammar and syntax of the manuscript should be checked carefully. Please, find below some specific comments.

Specific comments

Introduction:
The literature review on modeling of river water temperature should be expanded and updated including the most recent studies in this field. Besides "classical" deterministic and statistical models, there is a wide range of models based on machine learning techniques or hybrid physically-based/statistical approaches (e.g., Sahoo et al., 2009; Toffolon and Piccolroaz, 2015; Sohrabi et al., 2017), which have been emerging in the last years. Despite it is not recent, I suggest giving a look to the review paper by Benyahya et al. (2007), which provides a good overview of deterministic and statistical models used in the field of river water temperature prediction. Another useful and more recent paper is that by Gallice et al. (2015). In addition, the authors should refer also to existing literature on the assessment of anthropogenic impact on river water temperature (e.g., Cai et al., 2018; Gaudard et al., 2018; Raman Vinna et al., 2018, just to cite some recent papers).

In general, I believe that the paragraph from P1, line 19 to P2, line 8, should be thoroughly restructured and revised, and the authors should be more precise throughout the text (e.g., at P1, line 22: I believe that the authors intend deterministic and statistical models here; at P2, lines 21-23, the sentence is unclear; at P2, lines 25-26, the comment is superfluous since in a multiple linear regression, such as the one used by the authors, these components are obviously neglected).

P2, lines 7-8: I would rephrase this sentence in more general terms, because the amount of variance in river water temperature explained by air temperature and streamflow are strongly dependent on the case study (hydrological regime, season, etc.). In this regard, the authors should expand the analysis of parameters a2 and a3 of their regression model.

The second half of the Introduction (from P2, line 16) should be moved to the methods section and should be improved, as in its current form it does not clearly describe how the authors set up their analysis, especially concerning the definition and use of RBT as an "indicator for industrial heat input" and the time resolution of the data used in the multiple linear regression analysis.

Figure 1
This figure should be updated with the location of the monitoring station and of the NPPs. The main course of the Rhine should also be indicated.

Section 2.1.
I agree on the comment about accuracy and precision, however I wonder if the measurements are affected by instrumental drift and, in case, if the dataset has been corrected accordingly. P3, line 9: this sentence is unclear. In general, I agree that water temperature is rather homogeneous at a river section if it has a compact geometry, while it may be non-uniform if the geometry is complex.

Section 2.2.
Here the authors used a constant flow speed to evaluate the flow time required to travel from a cell of the catchment to the catchment outlet. The authors should clarify how they selected this flow speed and if it is reasonable to assume a constant value (was this velocity the same for the four outlets?). I wonder about the methodological robustness of the approach proposed by the authors since they applied the same flow velocity to all cells pertaining to the catchment, thus both to hillslope and river network cells. In this regard, I also do not fully agree on the sentence at P5, lines 21-22 since before reaching the channel network, rainfall may follow different paths (infiltration,

runoff, etc.), thus exchanging heat with the surrounding environment and decreasing its correlation to Ta. P3, line 20 and P4, line 1: this sentence is unclear.

Section 2.3
The authors state that parameter a1 (the intercept) summarizes all effects that are not directly ascribable to Ta and Q, which "are mostly from anthropogenic sources". Personally, I do not agree that, in general, the value of a1 can be unequivocally related to anthropogenic factors. The authors should support this statement referring to previous literature on the topic. In this regard, a useful reading is Isaak et al (2011), where also the multiplicative interaction term has been included in the multiple linear regression model. Variables x_0, y_0, and t_t in eq 2 are not defined.

Table 2 (and corresponding description in the main text): the authors should provide details on why they assumed a linearly deceasing weighting factor instead of other weighting functions. While the weighting factors decreases with Δt, I expect that T_w is no more correlated to T_a after some time. The authors obtain the best results using the "Time lag" model instead of the "Time lag + weight" model, saying that the furthest and oldest T_a influences on T_w are still carried as information in the water mass (P9, lines 4-5). In my opinion, the real reason is that without assuming a deceasing weighting factor the authors increase the dependence of current river water temperature on previous conditions, thus implicitly accounting for the thermal inertia of the river. This is an important aspect controlling river water temperature, which is not explicitly included in the model proposed by the authors and that can be accounted for e.g., through autocorrelation terms (e.g., Caissie et al., 2001; Toffolon and Piccolroaz, 2015).

Control scenarios
I would use a different word than "scenarios" here, since these are not scenarios but different approaches to calculate T_c.

Section 2.4
The authors should explain how they calculated the heat input by NPP to the Rhine.

The section should be expanded, and the sentences harmonized to make the reading more fluid (too short sentences).

Figure 3 and Table 3
Figure 3 would benefit from the inclusion of the air temperature time series with the corresponding linear trends. This would be useful for better understanding the correlation between river water temperature and air temperature fluctuations, which are filtered out when using linear trends. In this regard, it would be useful to add the Pearson correlation coefficient between these two variables in Table 3. At P8, lines 12-15 it would be useful to compare the trends found by the authors with those of more recent studies.

Tables 4 and 5
Why did the authors use the "Time lag+weight" approach for all other results instead of the "Time lag" approach, which performed the best? It should be clearly indicated if the RMSE and NSC refer to daily or annual values.

Section 3.3
It is unclear how the authors evaluated RBT over time. Did I correctly understand that they applied the multiple linear regression model for overlapping two-year time windows shifted by one month? What was the rationale of assuming two-year time windows instead of longer periods? Are the results affected by the length of the time window used for this analysis? P10, line 2 and P11, line 4: these sentences are qualitative, and not sufficiently supported by the results. The comment on the effect of alpine lakes is not well connected to the rest of the paragraph and should be expanded with some more detailed discussion. Eq 10 is dimensionally not consistent. How did the authors select the periods in Table 6? The authors could do the same calculation in continuous, for the entire period when the data are available (e.g., using the same two-year time windows as before). P11, line 16: what is the BASF company? This should be explained. Why RBT in Figures 4 and 5 are different? How sensitive are the results of the correlation analysis to the filtering of the data? How the filtering parameters have

been chosen and why 480 days has been used to shift the GDP-change time series? This number seems quite arbitrary.

Appendices
Appendices could be moved to the main text. In particular, the sentences in Appendix B should be revised because they have some syntax errors and typos. Figures A1 and A2 are inverted and the caption is the same. The analysis of parameters a_2 and a_3 should be deepened and moved to the main text.

Technical corrections

P1, line 13: "but an" –> "but is an". Is "means of production" an appropriate term in this context?

P2, line 3 and following lines: the use of "Ta –> Tw" is informal and should be modified.

P2, line 8: "hydro-logical" –> "hydrological"

P2, lines 8-9: a reference is needed here.

P2, line 16: is "revise" the most appropriate term here?

P2, line 20: "almost ideal" –> "ideal", "interesting", "meaningful"

P4, line 13: "followed, by" –> "followed by". Please, thoroughly revise the punctuation throughout the article (use of commas, missing close-brackets, etc).

P5, line 17: "ptovided" –> "provided"

P6, line 1: I would say that authors present four T_c calculations, not two.

P6, line 18: "heat input by NPPsto the Rhine" –> "heat input by NPP to the Rhine"

P8, line 5: "(0.0350 $^{\circ}Cy^{-1}$)" –> "(0.0489 $^{\circ}Cy^{-1}$)"

P10, line 15: "over the a time period" –> "over a time period"

P11, line 1: "shorter timer scale but do not seem,to our" –> "shorter time scale but do not seem, to our"

P11, line 14: "A a discontinuity" –> "A discontinuity"

P11, line 19: "by a by a" –> "by a"

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