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Title: The thermal peak: A simple stream temperature metric at regional scale
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Responses to Referees

Anonymous Referee #2:

We thank Referee #2 for their detailed review of our manuscript. We have broken out your individual comments, which are numbered, and responded to each accordingly in blue. We hope that our comments address and clarify any issues or concerns that they may have.

Comments

In Beaufort et al. the authors compiled stream temperature data for the entirety of France and Corsica, calculated an ecologically relevant summarizing metric ("the thermal peak"), and compared predictive models and an air proxy to determine the best model structure and predictor variables for extrapolating the thermal peak metric to all rivers in France/Corsica. Although the work done within is a valuable contribution, the manuscript would be improved by (1) altering the climate-change framing of the paper, (2) including a specific question or hypothesis, and (3) increasing specificity and clarity of the presentation. Regarding the first point, the paper frames the research as important for understanding stream thermal regimes under climate change. However, the authors calculate a metric which does not help us understand how climate change alters stream temperatures. This is a major issue. Additionally, there lacks a clear question or hypothesis in the introduction – another major issue.

We agree that the manuscript would be improved by reducing the focus on climate change in-of-itself, and honing the Introductory rationale towards the need to improved stream temperature datasets (our contribution) while acknowledging that climate change as the motivating driver. We also agree that ending the Introduction with a question and hypothesis will create a stronger rationale for our approach. Please see below for our more specific changes that will be made.

1. Comments regarding emphasis on climate change:
   The introduction leads me to think that the authors would be explaining how stream temperature is changing in France/Corsica as a result of climate change.

For example, see: Line 36-37: "However, the magnitude and direction of these expected changes will depend strongly on patterns of stream temperature change"

Line 38: "Hence it is critical to describe and analyze the spatiotemporal variability of river thermal regimes."

Line 71-74: "Indeed, stream temperature metrics that focus on extreme periods […] are likely adequate to understand trends of increasing pressures on aquatic ecosystems."

And in the Methods: Line 102-103: "To address ecologically meaningful temperature metrics under climate change, we focused on the two hottest stream temperature months, …" However, the metric the authors calculate does not describe temporal stream temperature changes. The described calculation of the thermal peak is an average of peak temperature across years for each logging station. The metric is thus only useful for understanding the spatial pattern of the thermal peak across France/Corsica for the years in this study. Although the compiled database itself may be a useful source for studies on climate change, the thermal peak metric calculated in this study does not describe changes in stream temperature through time.

Indeed, the authors even admit to this shortcoming in the discussion: Line 315-316: "The downside of the current approach is that it remains based on interannual metrics. Indeed, the non-concomitance of the time series does not allow us to compare extreme years (hot vs. cold)." More emphasis should be put on the thermal peak being a good comparison metric for rivers across space and may help managers understand which rivers currently exceed thermal tolerances of important biota.

These are all good points and we will alter the Introduction and Discussion accordingly. We will focus more on the main point of the paper throughout, which is the creation of a homogenous stream temperature database and the development of a simple metric to understand spatial variation in extremes, which of course, are a result of increasing air temperature due to climate change. Hence, we will remove/edit most of the referenced text here so that the objective is clear. We also will add text to lead to the eventual comparison of stream temperature records/extrapolation with air temperature, as our dataset offers an important improvement over often-used air-temperature proxies.

2. Comments regarding lack of question/hypothesis:

a. An objective is stated in the introduction (Line 73-74) but no specific question, hypothesis or prediction is explained. This left me wondering throughout the paper what the purpose of the research was. What questions motivated this research? What did you expect to learn from research at hand? What do you expect the thermal peak tell us about rivers in France/Corsica?

We agree that these additions will improve the rationale for this work, and we will include the following question and hypothesis in the Introduction. What are the spatial patterns of stream temperature extremes in France and their drivers, and are these patterns consistent across modeling approaches? We hypothesized that spatial patterns would be consistent, whereas the drivers would depend on the modeling approach used. We also hypothesized that stream size, air temperature, and groundwater contributions would emerge as important regardless of approach. Overall, we maintain our objective to create a harmonized database of daily stream temperature in France over the recent decade of warming as an important result of this work. We will demonstrate the importance of this result now by focusing the Introduction more on the current lack of such databases in the literature.

To evaluate our hypothesis, we will include an additional result showing the direction and magnitude of variable effects on the thermal peak (i.e., not just the variable importance for each model) that will allow us to evaluate their influence. To illustrate an example result here, we will compare the spatial variability of the thermal peak in relation to air temperature and stream size (see below).

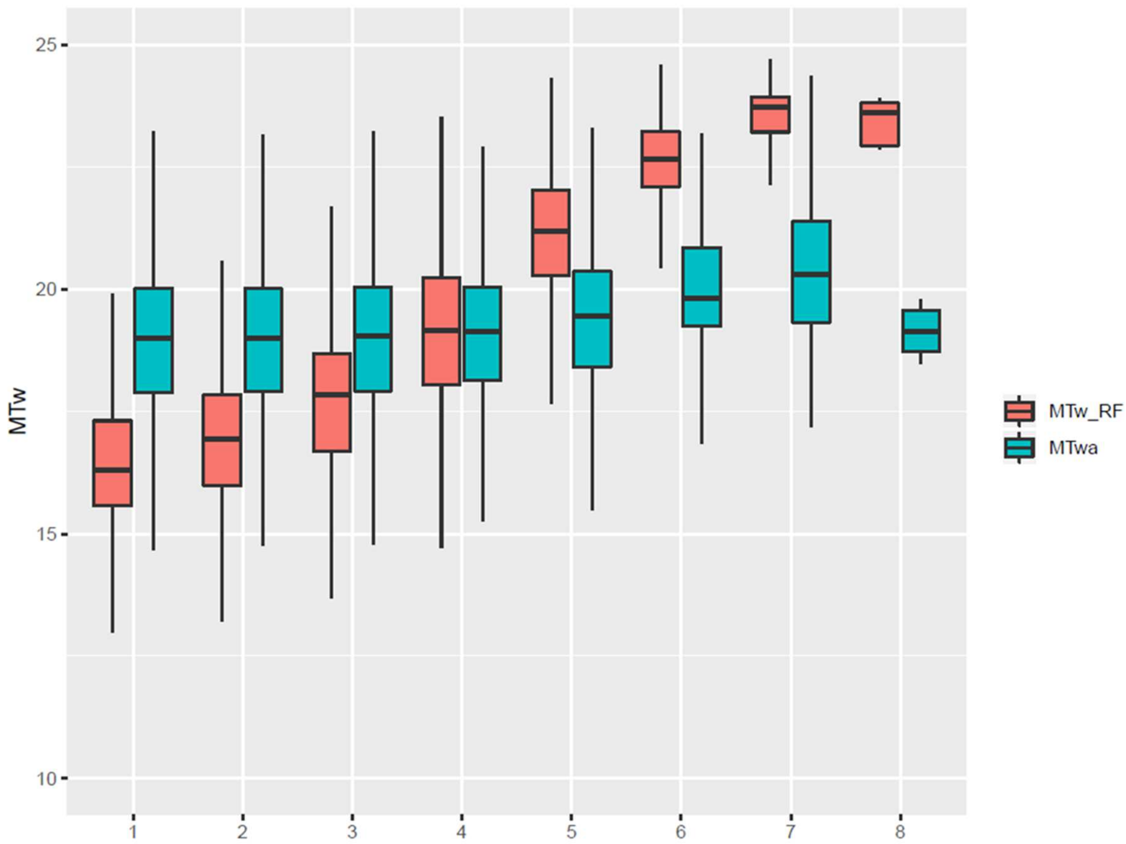


Figure showing the reach distributions of thermal peaks (y-axis) for random-forest-modeled stream temperature (red) and air temperature (blue) as a function of stream order (x-axis). We can see that whereas thermal peaks based on air temperature are insensitive to stream order, those based on stream temperature rapidly increase with stream order. Importantly, below Strahler order 5, stream temperature thermal peaks are less than air temperature, but this trend reverses for larger rivers. Hence, we can see that stream thermal peaks are more sensitive to network location than to air temperature.

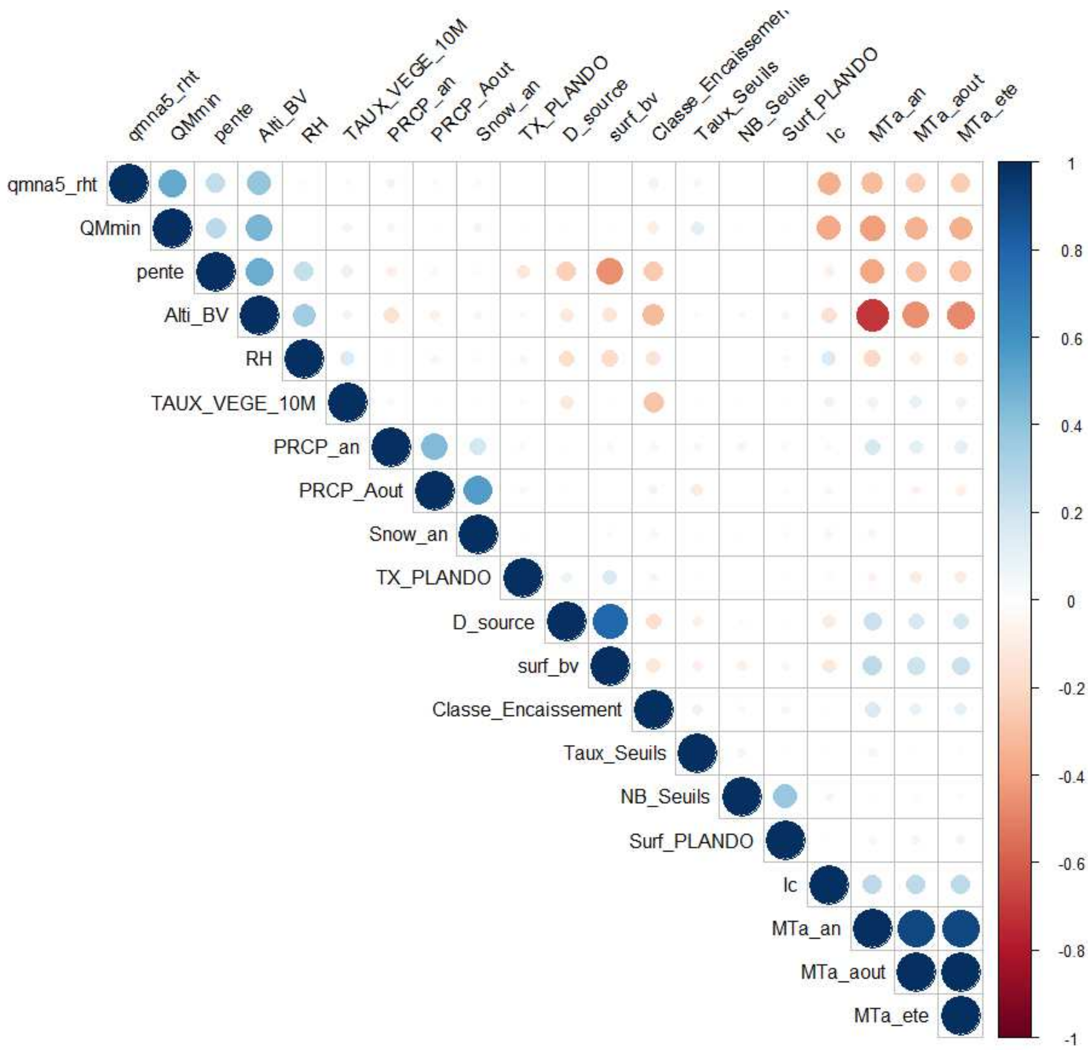
b. Section 4.3 of the discussion aims to attach meaning to the most important explanatory variables across each model. There was no hypothesis about which explanatory variables were thought to be the most important predictors, therefore it seems the authors are fishing for an explanation without having a clear question, hypothesis or prediction about these explanatory variables. Since the author's purpose for making these models was to predict the thermal peak across all rivers of France/Corsica, it is inappropriate to interpret the explanatory variables in this way.

We agree that variable selection was not clear in original text. We will improve our rationale for the explanatory variables used by being more explicit in our questions and hypothesis (see our response above), and by including specific hypothesized effects for each variable in Table 2 (see below). Indeed, each variable has a precedent for controlling stream temperature in the literature and was evaluated for collinearity (see correlation matrix that will now be in the Supplementary Material) before application in the models. We also now include more text in the Methods providing rationale for our variable choices, where some of the variables have substantial literature support, some have more recent, but less tested support (i.e., effects of ponds and weirs), and some we chose to test in this paper (i.e., concavity index and hydrological regime). These clarifications in our rationale for variable selection allow us to more readily attach meaning to their relative importance and effect direction (on T_p) in the Discussion.

Table 2. List of explanatory variables used in models.

Category	Variable	Notation	Source	Possible effect
Climate	Mean annual precipitation (2009 –2017) [mm]	P_{annual}	SAFRAN	Contrast between climatic regimes (Moore et al, 2013)
	Mean summer precipitation, July–August (2009 –2017) [mm]	P_{summer}	SAFRAN	Influence of heat budget Caissie, 2006
	Mean annual snow accumulation (2009 –2017) [mm]	S_{annual}	SAFRAN	Heat budget, meltwater influence, Caissie, 2006, Webb et al, 2008
	Mean summer air temperature, July–August (2009 –2017) [°C]	T_{summer}	SAFRAN	Positive effect related to heat budget, relative Moore et al, 2013 (index of the thermal summer climate)
Hydrology	Mean annual specific discharges [$L\ s^{-1}\ km^{-2}$]	Q_{mean}	RHT	Thermal capacity influence, Caissie, 2006
	Mean monthly minimum specific discharge with a return period of 5 years* [$L\ s^{-1}\ km^{-2}$]	q_{min}	RHT	Proxy of base flow index, Chang and Psaris, 2013
	Concavity index† [-]	CI	RHT	Proxy of water storage in the catchment (snow or groundwater), tested in this paper
	Hydrological regime‡ [-]	HR	RHT	Contrast between hydrological regimes, tested in this paper
Catchment characteristics	Mean catchment elevation [m]	elev	RHT	Negative effect given the relation with air temperature (Isaak and Hubert, 2001)
	Drainage area [km²]	area	RHT	Proxy for width-depth ratio of streams (Hrachowitz et al, 2010), and thermal capacity (Imholt et al, 2013)
	Mean streams slope over the catchment [$m\ km^{-1}$]	slope	RHT	Affict river hydraulics and thus thermal advection and exposure time to incoming radiation (Daigle et al, 2010)
	Riparian vegetation cover ratio in 10 meters buffer (%)**	veg	SYRAH	Negative effect, as decrease exposure to diurnal radiation (Moore et al, 2005)
	Linear weir density upstream of stations (# km^{-1})**	weirs	SYRAH	Potentially heating effect (Chandesris et al, 2019)
	Areal weir density upstream of stations (# km^{-2})**	weir area	SYRAH	Potentially heating effect (Chandesris et al, 2019)
	Pond cover ratio upstream of stations (%)**	ponds	SYRAH	Potentially heating effect when ponds and shallow reservoirs release warm water from overflow (Seyedhasemi et al, 2021)

Stream incision class **	SI	SYRAH	Potential proxy of exchange of water with hyporheic environment, Webb et al, 2008



3. Comments regarding improvements on clarity and specificity:

a. Line 88, sentence starting with "Hence, our main challenge was to pool...": This sentence was difficult to understand. Improve with a more thorough explanation, possibly breaking up this sentence into multiple.

We agree this is confusing. We will clarify that the challenge was coalescing and harmonizing all the disparate data sources.

b. Line 99, "data were … averaged into mean daily stream temperature data". Do you mean "daily mean" here? It is unclear if it is meant to be the mean daily temperature (averaged across years for a particular day) or the daily mean temperature (average temperature of a specific date).

Indeed, we meant the latter: that the means of hourly data were taken to achieve daily mean temperatures. We will be more clear here.

c. Line 100, “1) hourly Tw anomalies”. If Tw is defined as the daily mean temperature, how can you see hourly anomalies if there is one mean temperature per day? May need to define another variable to use here.

Thank you for catching this. We will change this to “hourly stream temperature anomalies” to avoid conflating Tw with the hourly data.

d. Line 101, “Tair”: Need to define this variable because it is the first time it is used.

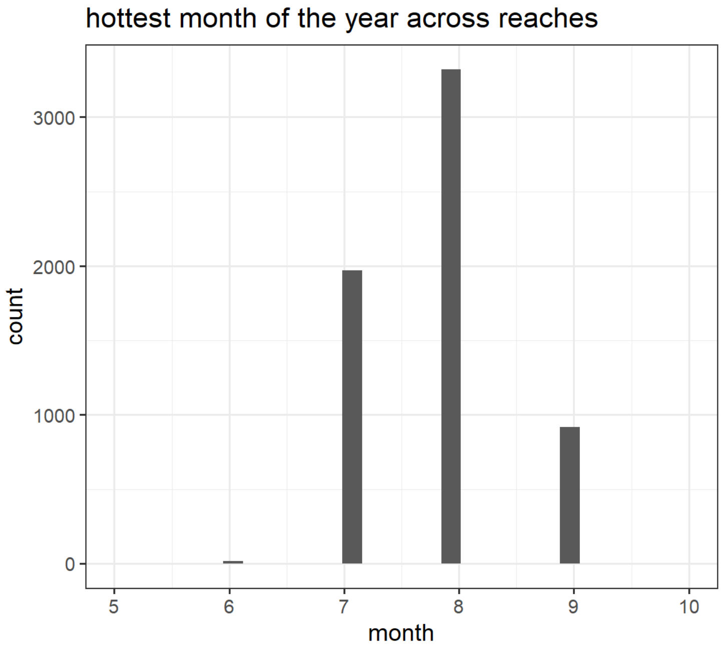
Fixed.

e. Section 2.2, first paragraph. Why hold back on defining the “simple metric” within the first sentence? It is odd to hold back on defining the metric and then reveal the big mystery of what the metric is.

We do not quite follow this comment, but we will add “…, the thermal peak.” In the first sentence to clarify.

f. Section 2.2, second paragraph. $\overline{Tw,30}$ is defined as the “mean temperature of the 30 hottest consecutive days of each year”. However, the data have already be constrained to July and August. How can you be sure that the 30 hottest consecutive days occur completely within the window between July 1 and August 31? In the last sentence you conclude that the hottest day of the year always occurred between July 28 and August 30. This implies that for the temperature time-series in which August 30th is the hottest day of the year, the 30 hottest consecutive days would include days in September. So, $\overline{Tw,30}$ should be re-defined in the paper as the mean temperature of the 30 hottest consecutive days in July and August. Be more specific about defining $\overline{Tw,30}$.

We now include in the Supplementary Material that our analysis shows that July and August are generally the hottest months of the year (see below for analysis on stations with annual data). Importantly, many of the stations, particularly those operated by fishing agencies, only have July and August data, which we will precise in the Methods. We agree that we should be more specific and clear in this section and will make the appropriate changes to the text noting that analyses are constrained to July and August. To support our approach, we will also include a sensitivity analysis on the sites with annual data where we compare the T_p of the annual time series with the T_p limited to July and August.



g. Line 164, “SAFRAN data”. Define what this data is.

We will include a definition in text that explains the following: (Système d’analyse fournissant des renseignements atmosphériques à la neige) is a mesoscale atmospheric analysis system for surface variables with reanalysis data at hourly time steps using ground data observations. Originally intended for mountainous areas, it was later extended to cover France. The detailed description can be found in Durand et al. (1993, 2009).

h. Line 198, “… all possible variables.” Very broad. More specificity would be helpful, such as “all possible variables characterized in Table 2.”

Agreed.

i. Line 236-238, “This bias … in the regressions.” These sentences are difficult to understand. Be more specific to improve clarity. The ending of one sentence is “…with only one year of observation.”, and the next sentence begins, “In contrast, when there is only one year available…”. These aren’t contrasting clauses, thus making it difficult to understand what is being contrasted.

Agreed, we will improve clarity here.

j. Sentence starting on line 260, ending line 263, "The two most relevant…". Break into 2 sentences to improve clarity.

Agreed, we will improve clarity here.

k. Line 281: use of 14°C. Explain why 14°C important and why this value chosen as a cut-off point.

This was predominately chosen for ease of visualization. We will explain this in the figure and in text.

l. Figure 6C. Figure 6c shows probability distributions for extrapolated thermal peak. Firstly, the bins are not of equal size: the first bin (labelled <14) includes all temperatures between 6.3 (minimum temperature reported on line 277) and 14, a range of 7.7 degrees; the second through fifth bin have ranges of 3 degrees; and the final bin includes temperatures from 22 to 27, a range of 5 degrees. The 14- and 22-degree cutoff is not explained and thus seems arbitrary. Secondly, since temperature is continuous, it shouldn't be binned in this way, unless for some specific reason. Continuous distributions should be portrayed as "probability density functions". Each model would then have a continuous distribution, and each can be plotted on the same graph for comparison.

Originally, it was made this way to correspond to the cut-bins in Figure 5, which were made to best visualize the temperature distributions. We will made the requested edits to the figure.

m. Line 301, first sentence in discussion. Be more specific about the timeframe of the dataset: "the largest, regional summertime stream temperature datasets"

Agreed, we will include the timeframe of 2008–2018.

n. Line 326. Which "metrics based on observations", specifically, are you comparing to estimates of Tp?

We will more specifically refer to the fact the thermal peak calculated with observed data containing gaps $T_{p,obs}$ (i.e., without the climate correction) has larger biases than thermal peaks calculated with observations that are climate corrected $T_{p,fill}$

o. Line 328. Further explain what is meant by "when applied at scale". How does that relate to figure 6B?

Good point, removed.

p. Line 352: “Higher minimum flows” would make more sense than “Larger minimum flows”

Agreed and changed.

q. Line 354: Change “greater” to “more”. “Great” implies a quality of shade and not a quantity. “More” implies a quantity.

Agreed and changed.

4. Technical Corrections

a. Line 21: Use of “However” does not belong because this sentence doesn’t relate to previous

b. Line 27: “…, and decomposition rates, and dictates animal … “

c. Line 33: “and levels” is repetitious with flows

d. Line 96: “… were previously…” change to “have been”. “were previously” implies that a different study excluded these data. If that is the case, cite that study.

e. Line 155: “is not clear” should be “was not clear”

f. Line 221, equation 7: regression coefficient “a” is in the equation twice and “c” is missing.

g. Line 229: “cross-validation this 100 times”

h. Line 321: insert “between” between “correlation” and “Tair”

i. Line 325: remove “particularly”

j. Line 326: remove “a robust interannual metric”. Only need to say “... sufficient to estimate Tp”

k. Line 329: change “to” to “of” in “climate corrections to temperature metrics”

l. Line 352: change “following” to “followed”

m. Line 373: change “representativeness” to “representation”

All suggested technical corrections will be made.