DEVELOPMENT OF TWO INDICES FOR THE QUANTIFICATION OF THERMOPEAKING ALTERATIONS IN ALPINE RIVERS

ANNUNZIATO SIVIGLIA
Laboratory of Hydraulics, Hydrology and Glaciology, Swiss Federal Institute of Technology. Hönggerbergring 26, 8093 Zurich, Switzerland.

DAVIDE VANZO
Department of Civil, Environmental and Mechanical Engineering, University of Trento. via Mesiano 77, 38123 Trento, Italy.
Laboratory of Hydraulics, Hydrology and Glaciology, Swiss Federal Institute of Technology. Hönggerbergring 26, 8093 Zurich, Switzerland.

MAURO CAROLLI
Department of Civil, Environmental and Mechanical Engineering, University of Trento. via Mesiano 77, 38123 Trento, Italy.

GUIDO ZOLEZZI
Department of Civil, Environmental and Mechanical Engineering, University of Trento. via Mesiano 77, 38123 Trento, Italy.

We propose two new indices able to quantify the sub-daily thermal alterations induced by the release of hypolimnetic water for hydropower production (thermopeaking). They are derived from the analysis of water temperature data for a given gauged station and quantify the i) sub-daily thermal rate of change and ii) the frequencies of oscillations contained in the thermal signal. We analyse the data from two different thermal datasets (Italy and Switzerland) for a total of 48 stations with 10 minutes time resolution of temperature data. The stations were grouped according to the absence of upstream hydropeaking releases (reference group) and the presence of upstream hydropeaking, hence potentially impacted by thermopeaking (altered group). Using a simple statistical approach, based on a non-parametric definition of outliers, we identified the range of variability of the two indices for the reference group. In the space of these two indices it is possible to identify three different classes of thermal alteration: absent or low, medium and high.

1 INTRODUCTION

River water temperature is an important physical property of flowing waters and is widely recognized as a key driver in aquatic ecosystems (e.g. [2], [11]) and its variability at multiple temporal scales defines the thermal regime of a river. Alterations of the thermal regime at any of these temporal scales can adversely affect the river biota and ecosystem processes (e.g. [1], [4], [5], [10]). Thermal regime alterations due to anthropogenic interventions have been recorded and investigated at different time scales (e.g. [6]). However, little attention has been devoted to sub-daily thermal alteration so far and in this work we focus on thermal alterations induced by the release of hypolimnetic water for hydropower production, namely thermopeaking (e.g. [3], [12]).The aim of this study is to design two quantitative indicators which are capable of disentangling between thermo-peaked and thermo-unpeaked river reaches and we design a methodology to distinguish between different levels of "thermo-peaking alteration" which: i) can be easily computed from temperature time series which are those commonly available at sub-daily sampling resolution; ii) allows comparison among different stations in the same area; iii) is statistically robust.

The details of the derivation of the two indices and all the results are fully presented in [9].

2 METHODS

2.1 Dataset

The entire available dataset is composed by 48 river temperature sampling stations: 40 Swiss stations and 8 Italian stations in the Autonomous Province of Trento. Swiss records are 6-year long (2007-2012) while the Italian records refer to year 2007; both time series have a breakdown of 10 minutes. Within the dataset we identify the stations without upstream hydropower plant intermittent water releases and adopt them as a reference group of non-impacted stations (dataset details in [9]).

2.2 Indicators

Thermopeaking alterations are linked to repeated daily or sub-daily water releases (hydropeaking) and they appear in the form of additional sharp and temporary increases/decreases of water temperature superimposed to the non-altered local thermal trend (see example in Figure 1). Therefore, the thermopeaking signature on river thermograph is expected to increase the magnitude of short-scale, sub-daily temperature variations and the frequency of thermal oscillations at sub-daily scale. Hence we propose two different indicators to capture the alteration of sub-daily temperature rate of change and of the frequency of sub-daily thermal oscillations, respectively.

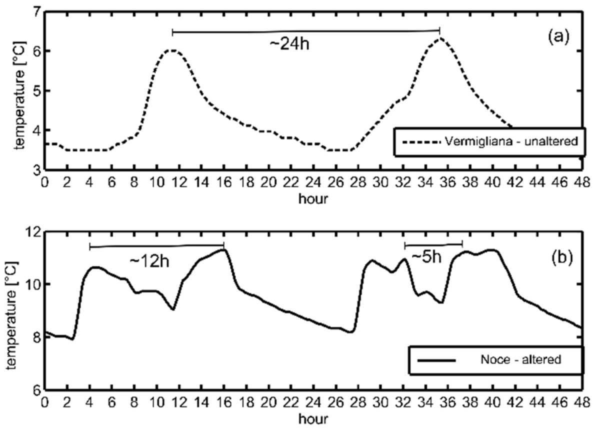

Figure 1 Example of a 48-hours thermograph for an unaltered station (a) and an altered one (b).

The first indicator TP_Δ aims at quantifying the temperature rate of change over sub-daily time scales. For a given sub-daily time interval Δt and for a *i-th* day, the daily indicator $TP_{\Delta,i}$ is defined as

$$\mathrm{TP}_{\Delta,i} = \frac{\max|T_{k+\Delta t} - T_k|}{T_{\max,i} - T_{\min,i}} \quad (1)$$

where *k* refers to every temperature reading. For a given gauging station, the TP_Δ indicator is defined as the median value of the $TP_{\Delta,i}$ distribution. The typical duration of temperature variations strongly depends on turbine operational procedures: turbine switch on/off last in about 15-60 minutes (see for example Figure 1b), hence, in order to catch the largest short-scale temperature variations, Δt is chosen equal to 30 minutes.

The second indicator TP_{En} aims at quantifying the frequency of the sub-daily oscillations by adopting the Power Spectral Density (hereinafter PSD, e.g. [7]) of the thermal signal as a proxy for the number and relevance of sub-daily thermal fluctuations. Formally, the indicator TP_{En}, represents the ratio between the short scale and the daily scale spectral power of oscillation for the considered station, i.e.:

$$TP_{En} = \frac{P_n}{P_{24}} \quad (2)$$

where P_n and P_{24} are the averaged power of the PSD for a frequency band of *n* (with *n*=6 hours) and 24 hours, respectively. We assume the fluctuation period *n=6* hours to be representative for hydropeaking events (e.g. Figure 6 in [12]), which typically range between some hours to daily scales in accordance with electricity demand.

Aiming at quantify the sub-daily thermal alterations with reference to an unaltered group, we assess the range of variability of both indicators for unaltered thermal regimes via a statistical outlier approach. Hence, for a reference population of unaltered stations, if an altered investigated station is outlier of the reference population, it has to be considered as significantly thermally altered. We adopt a standard non-parametric outlier definition (e.g. [8]) in order to avoid a priori assumptions on the normality distribution of data. The statistical approach provides one threshold for each indicator which represents the range of variability of the reference (unaltered) group.

The dependence of thermal regime on local physiographic characteristics is well-established (e.g. [2],[11]), however, in order to allow reciprocal comparisons between different stations, the values of the designed indicators have to return little dependency from the local physiographic features of the stations. The normalization adopted in the indicator design (Equation (1) and (2)) allows the filtering out of the influence of the considered physiographic characteristics, namely the station elevation, the basin area and mean elevation, the glacier cover and the mean discharge. The details of this analysis are given in [9].

3 RESULTS

We classify the stations of the altered group with respect to the derived thresholds. Figure 2 shows the stations belonging to the altered group in the space of the two indicators (stations are labelled according to [9]). The two thresholds (vertical and horizontal dashed lines) divide the space in 3 main classes of thermal alteration: absence (A), moderate (B_1 and B_2) and strong (C).

Within the investigated 19 altered stations, some of them reveal no thermal alteration due to thermopeaking and lay in region A, i.e. they have short-scale temperature variations and oscillation period statistically similar to those recorded in the reference group. Some other stations fall in region B_1 (moderate alteration) but none in region B_2. This latter observation suggests that there are cases with non-natural sub-daily thermal fluctuations of small amplitude, while large temperature variations do not occur without altering also the dominant, daily oscillation period. Finally, the most thermally altered stations lay in region C, i.e. they have magnitude and frequency of sub-daily thermal alterations different from the reference group.

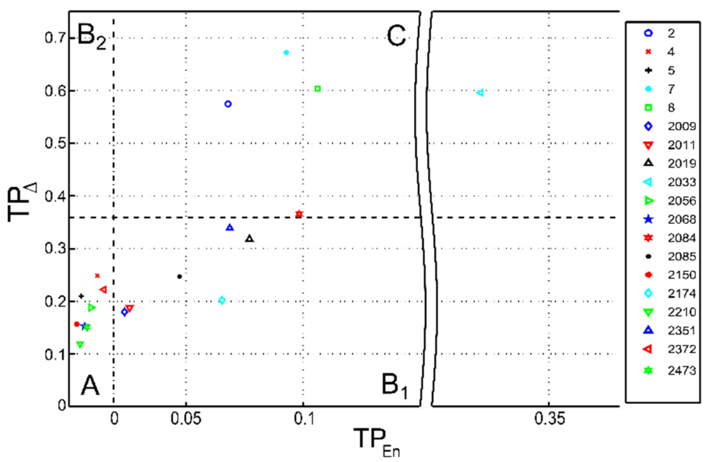

Figure 2 Indicators TP_{En} and TP_{Δ} for the altered stations; for the station labels refers to [9].

4 CONCLUSIONS

The proposed indicators allow at-a-station quantification of the degree of sub-daily thermal regime alterations due to thermopeaking. Moreover the methodology allows the direct comparison among different gauging stations. Such approach overcomes the need of having temperature records both upstream and downstream of each hydropower plant water restitution to evaluate the alteration of thermal regime. The methodology presented here can be adopted as first a screening tool for environmental managers to identify and quantify at-a-station river thermal alterations, thus providing a powerful mapping tool to identify priorities and critical locations.

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