A Methodology for Air Temperature Extrema Characterization Pertinent to Improving the Accuracy of Climatological Analyses

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The suggested methodology for the characterization of temperature extrema presents a multistep preprocessing procedure intended to derive extrema time series of correctly identified and thermally defined daily air temperature extrema pairs. The underlying conceptual framework for this approach was developed in response to the existing gaps in the current state of daily extrema identification and the development of extrema-based synthetic air temperature time series. A code consisting of a series of algorithms was developed to establish four-parameter criteria for a more accurate representation of daily variability that allows easy replication of temperature distribution based on the correct characterization of daily temperature patterns. The first preprocessing step consists of subjecting the high-frequency temperature time series to a theoretical diurnal observing window that imposes latitudinally and seasonally crafted limits for the individual identification of daily minima and maxima. The following pre-processing step involves the supplementation of air temperature extrema with the information on the occurrence of extrema timing deemed as vital information for the reconstruction of the temperature time series. The subsequent step involves the application of an innovative temperature pattern recognition algorithm that identifies physically homogeneous air temperature populations based on the information obtained in previous steps. The last step involves the use of a metric for the assessment of extrema temperature and timing parameters' susceptibility to climate change. The application of the presented procedure to high-frequency temperature data yields two strains of physically homogeneous extrema time series with the preserved characteristics of the overall temperature variability. In the present form, individual elements of this methodology are applicable for correcting historical sampling and air temperature averaging biases, improving the reproducibility of daily air temperature variation, and enhancing the performance of temperature index formulae based on daily temperature extrema. The objective of this analysis is the eventual implementation of the presented methodology into the practice of systematic temperature extrema identification and preprocessing of temperature time series for the configuration of physically homogeneous air temperature subpopulations.

air temperature minimum maximum analysis

The accurate identification of air temperature and the abundance of sources of error in daily observation practices remain a current subject in the scientific literature [1][2][3][4][5][6][7][8][9]. In addition, the common scarcity of high-resolution temperature data naturally transfers the reliance on daily minima and maxima for the variety of scientific evaluations. Furthermore, the extensive scope of climatological analyses, climate change impact assessments, and future climate projections rely upon rigor in the identification of daily temperature extrema. With this in mind, it would be expected that the determination of daily extrema from high-frequency data sets is straightforward.

However, the long-term comparative analysis of continuous temperature measurements with derived daily extrema reveals a lack of agreement resulting in a large negative temperature bias in daily minima [10]. The ultimate goal of identifying daily extrema is the summarization of temperature variability into the smallest number of representative data points. However, the assumption that daily minima and maxima contain sufficient information to correctly characterize diurnal air temperature variability is not always justifiable [5]. The systematic application of a discrete extrema search, or the use of MIN/MAX functions to identify the lowest and the highest values for a specified range, entails a number of pitfalls associated with selecting the initial point and the length of the search interval [10]. The same principle extends to daily extrema observations given below.

The definition of the starting point of the observational window for daily extrema identification has been a constant source of uncertainty throughout Canadian temperature recording history. The common mischaracterization of diurnal minima, caused by the old observational window, initiated a Canada-wide redefinition of the observing time for temperature recording. On 1 July, 1961, the climatological day was redefined at all Canadian synoptic stations to end at 6:00 UTC. However, the change in the observing window did not result in the anticipated alleviation of the observational bias. The shifting of the initial point instead introduced a cold bias to the observations, by affecting 15% to 38% of days in Canada annually by increasing the potential for recording minimal temperatures on two consecutive days. The bias in daily minima was observed to be more pronounced in the eastern regions of Canada [11][12][13]. Variations in the time limits of the day, i.e., the differences in the definition of a beginning and the end of the “day”, have been known to affect the quality of recording of a daily air temperature minimum in general [14][15].

The need for the development of the new methodology first became apparent through the examination of the relationship between diurnal air temperature variability and the degree-day snowmelt volume estimation [16]. The unavailability of continuous air temperature data and frequent encounters with missing data, affecting the quality of daily snowmelt water equivalent estimation, raised the need for the development of air temperature approximating methods for the improvement of the degree-day formula. The search for an analytical solution for the reproduction of the temperature–time dependence curve identified the need for an accurate sequence of extrema as the key input for a successful air temperature approximation. However, the attempt to identify chronologically ordered extrema using discretized methods has proven to be a surprisingly complex task, yielding frequently mischaracterized and ‘reverse-ordered’ extrema. More specifically, the sequence of minima and maxima, necessary for the reproduction of air temperature, is often reversed due to the omission of a local minimum which the traditional method of extrema identification misses because it does not represent the lowest temperature of the day. The implications of mischaracterized extrema and ensuing extrema sequence result in low performance of the degree-day formula commonly used in various climatological, hydrological, agricultural, and civil engineering applications [17][18][19][20][21][22][23][24][25][26]. The comparison of measured and reproduced temperature series, based on the correct extrema sequence, cast doubt on the accuracy of identified diurnal extrema using the current observing window and pointed to the knowledge gap in discrete extrema identification. These findings led to the conceptualization of the Climatological Observing Window (COW) and the creation of a code for the automated processing of high-frequency temperature time series into accurate chronologically ordered extrema time series [10].

A related observation that led to the further development of this methodology was the recognition of the role of the timing of daily extrema occurrence in the improvement of the accuracy of daily temperature replication with analytical approximations. It became apparent that the ongoing search for the improvement of the reproduction of the diurnal temperature variability in fact represented an indirect pursuit for the missing element in daily temperature reporting, i.e., the exact timing of diurnal extrema occurrence [27][28][29][30][31][32][33][34]. This consideration further unraveled the abundance of information in the turning points of the daily temperature–time curve and led to the attribution of a parameter status to the Diurnal Extrema Timing (DET) of a daily minimum and maximum temperature [35].

The third element of our methodology emerged from the platform developed for the establishment of the first two elements. The algorithms developed in the R programming language [36] in previous stages represented the basis for the detection of the physically heterogeneous nature of the air temperature extrema population. The development of the Linear Pattern Discrimination (LPD) algorithm enabled the separation of the complete temperature–time series into two homogeneous extrema temperature populations. The separation of the chronologically ordered daily extrema sequence into two homogeneous extrema populations uses the criterion derived from the timing of the extrema parameter. This criterion enabled the algorithmic recognition of the Diurnal Temperature Pattern, a concept conceived from the unique difference in the timing between two consecutive daily turning points on the temperature–time curve [37]. The extension of this concept into the seasonal analysis of radiative and advective temperature trends reveals specific indicators of temperature changes and thermal regimes of individual homogeneous temperature subpopulations [38].

The last element of the theoretical framework for extrema characterization represents the Climate Parameter Sensitivity Index (CPSI) devised to assess the warming trends in temperature and timing parameters of derived indices obtained from the previous three stages of the analysis [35]. A vulnerability assessment of temperature and timing indices uncovers a greater susceptibility of the timing parameter than temperature to climate change.

It is important to note that while this new methodology for extrema characterization remains open to additional advances in research development, the current state of its all elements is fully operational.

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