CHANGES AND TRENDS IN IDEAL HOLIDAY PERIOD BASED ON HOLIDAY CLIMATE INDEX APPLIED TO THE CARPATHIAN BASIN

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DOI: 10.21163/GT_ 2023.182.17

ABSTRACT:
The Holiday Climate Index (HCI) is a well-known and valued index for assessing the weather suitability of outdoor recreational activities. As a composite index, it takes into account many aspects of the weather, all of which affect the well-being of tourists. With the accentuation of climate change, the HCI plays an important role in the organization and planning of tourist activities. These plans must take into account not only the individual values of the index for different destinations, but also the sequence of days with certain expected values of the index. The aim of our research was to create a software module in R that would allow the analysis and identification of periods of consecutive days in which the HCI is above a certain minimum threshold and also has a minimum average value for that period. We applied this module to the analysis of historical (1970-2004) and present and near-future (2005-2040) HCI values in the EC-EARTH climate model, identifying for each year and location in the Carpathian Basin the starting day of the climatically best seven-day period. To obtain a time series for each location, we aggregated the values for the two periods using the mean, median, standard deviation and trend calculation. The analysis shows that the ideal time to start a holiday is not only changing, it is becoming increasingly unpredictable. Whereas in the 1970-2004 period there was a well-observed decreasing trend in the starting day, for the 2005-2040 period we see a trend-free situation in most of the area. Even where trends do appear, we find them in opposite directions in nearby areas, making it difficult to plan the ideal time to start a holiday.

Key-words: *Holiday Climate Index, Carpathian Basin, ideal touristic period, R Cran, automatized analysis*

1. INTRODUCTION

The Carpathian Basin comprises diverse natural and man-made landscapes, making it a favoured tourist destination. Sustainable tourism development is a crucial factor in the region's efforts to maintain and expand tourist activities (Dávid & Szűcs, 2009). A key element of sustainability concerns climate change, which affects the region owing to its location at the intersection of multiple climatic zones. The region generally encounters a continental climate marked by warm summers and chilly winters. Nevertheless, over the last few decades, the climate within the locality has significantly fluctuated (Rakonczai, 2011; Magyari, 2022; Mezősi et. al, 2014), rendering it one of the most fragile territories in Europe (Csete & Szécsi, 2012).

Tourism satisfaction depends on the climate, as demonstrated by previous studies (Gomez, 2005; Amelung et al., 2007) and the suitability of climate for tourist activities can be assessed using either the Tourism Climate Index (TCI) or the Holiday Climate Index (HCI). TCI, which was created by Mieczkowski in 1985, has been found to have limitations in recent years (Dubois et al., 2016). As a result, the new Holiday Climate Index (Scott et al., 2016) has been developed, which provides several advantages over TCI. The HCI takes into account six meteorological factors: average temperature, maximum temperature, minimum temperature, hours of sunshine, rainfall, and humidity. This

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includes all three aspects of tourism satisfaction in relation to the climate: comfort, aesthetics, and physical effects. The HCI is subsequently calculated as a weighted average of these six elements.

Due to the anticipated impact of climate change on tourism (Scott et al., 2012), the significance of the HCI has grown in the context of climate change. It allows for the evaluation of the vulnerability of tourism destinations to climate change and the formulation of strategies for adaptation (Yu et al., 2022).

HCI has gained popularity and its adaptation to different tourism segments, including beach, urban and winter sports tourism, has been pursued (Demiroglu et al., 2021). This renders it a significant contribution to research of specific tourism types, given the numerous studies that use it in diverse locations globally (Demiroglu et al., 2020; Amiranashvili et al., 2021; Yu et al., 2021; Saygili Araci et al., 2021, Samarasinghe et al., 2023).

Research in our study area focuses on HCI and is concentrated in two research groups, one located in Romania and the other in Hungary. In Romania, Velea et al. (2022) studied the correlation between tourist flow and urban HCI values from 2010 to 2018, finding a clear link between the two. In a near future period of 2021-2040, Velea et al. (2023) examined the climate suitability of various cities and rural tourist destinations for each season. The study estimated the impact of climate change on overnight stays. For research conducted in Hungary (Kovács et al., 2017; Kovács & Király), the TCI was enhanced to account for differences in seasonal thermal perception. This allowed for the calculation of the index's spatial distribution for various annual periods and months, thus enabling an interpretation of its evolution on a district level.

Climate-influenced tourism is significant for both the supply and demand sides (Öztürk & Gömal, 2018). Individuals wish to select an optimal consecutive period for their holiday based on weather conditions. Our study aims to create an automated data processing module that investigates the emergence and variation over time of the ideal seven-day period for vacation planning in the Carpathian Basin.

2. DATA AND METHODS

Our study is based on the Holiday Climate Index (HCI) which was accessible from the Copernicus Database (https://climate.copernicus.eu/climate-suitability-tourism). This index was obtainable as historical data, covering the time span from 1970 to 2004, and as climate model data, extending from 2005 to 2100. The research employed the EC-EARTH Global Climate Model combined with the intermediate scenario RCP4.5. The data format was NetCDF, with each downloadable file featuring data at a daily resolution for a period of five years. The dataset includes four variables per location per year: the daily index, the number of fair days, good days, and unfavorable days. It's noteworthy that the last three indices lack temporal linkage; we are uncertain about their timing and distribution. Our research aims to address this information gap. **Table 1** presents the index values and interpretation.

Table 1.

HCI index values and their interpretation.

HCI score	Interpretation	Copernicus variable
0-20	Dangerous	Unfavorable
20-40	Unacceptable	
40-50	Marginal	
50-60	Acceptable	Fair
60-70	Good	
70-80	Very good	Good
80-90	Excellent	
90-100	Ideal	

The initial phase involved extracting the study region from every datafile and merging the results to produce a single NetCDF file. The CDO (Climate Data Operator) tool was employed to accomplish this task, utilizing ***sellonlatbox*** and ***mergetime*** commands (Schulzweida, 2022). The full data processing procedure was developed in R through R Studio. Three additional extension packages were required to process the data: ***raster*** (Hijmans, 2023) for managing the HCI index raster layers, ***ncdf4*** (Pierce, 2022) for accessing the NetCDF raw data files, and ***wql*** (Jassby & Cloern, 2022) for determining trend significance.

The data processing algorithm contains the following steps (**Fig. 1**):

- for each year present in the dataset
    - extract of one year data
    - descale the extracted data
    - for each location in the study area
        - identify the best consecutive days having given thresholds for minimum HCI value and minimum mean HCI value through those days.

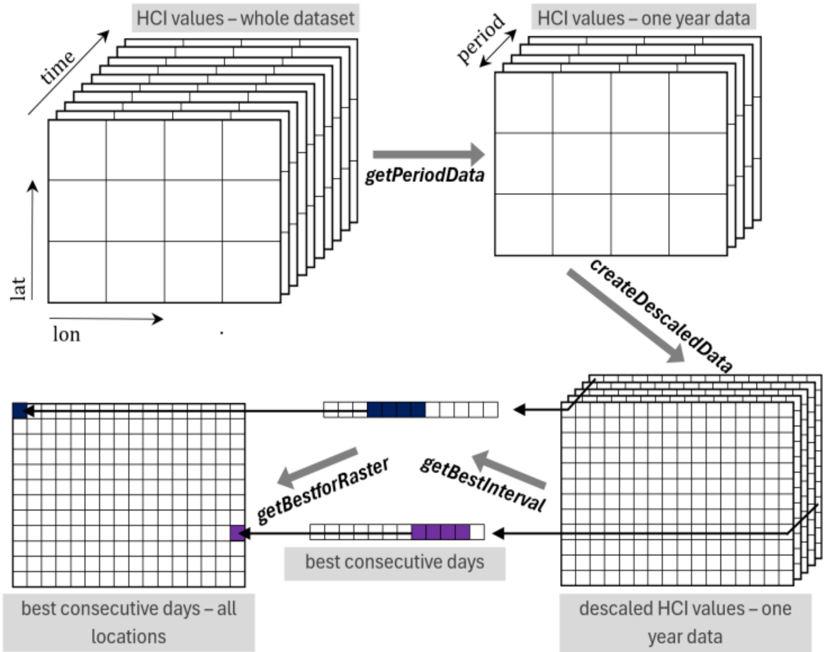


Fig. 1. Visual illustration of the data processing algorithm with the name of developed R functions.

The role of each function used in the algorithm is described below mentioning its role and parameters. The **getPeriodData** function returns the desired time period from a dataset (**Fig. 2**). The function's input parameters: ***dataset*** – original dataset with full data, ***firstDate*** – date of the first data in the whole dataset, ***startDate*** and ***endDate*** – date for the desired extraction period. The **createDescaledData** function returns the 1 km^2 spatial resolution variant of the raw dataset for a selected year (**Fig. 3**). The initial spatial resolution of the Copernicus dataset is 0.11°. With this function data descaling was realized on the fly only for the actually processed year by this saving memory which is important issue for such huge datasets.

```
getPeriodData <- function(dataSet,firstDate,startDate,endDate)
{
  startIdx <- startDate - firstDate + 1
  endIdx <- endDate - firstDate + 1
  return (dataSet[,,startIdx:endIdx])
}
```

Fig. 2. R code of the getPeriodData function.

```
createDescaledData <- function(hci,firstDate,year)
{
  values <- ncvar_get(hci,"hci-proj")
   fullStartDate <- as.Date(paste(year,"-01-01",sep=""))
  fullEndDate <- as.Date(paste(year,"-12-31",sep=""))
  selSet <- getPeriodData(values,firstDate,fullStartDate,
                                                    fullEndDate)
  lon <- ncvar_get(hci,"lon")
  lat <- ncvar_get(hci,"lat")
  nr <- nrow(selSet)
  nc <- ncol(selSet)
  l <- length(selSet[1,1,])
  finalSet <- array(0,dim=c(nr*8,nc*8,l))
  for(i in 1:l)
  {
    lyr <- raster(t(selSet[,,i]), xmn=min(lon), xmx=max(lon),
                  ymn=min(lat), ymx=max(lat), crs="+proj=longlat")
    lyr <- disaggregate(lyr,fact=8,method='bilinear')
    finalSet[,,i] <- getValues(lyr)
  }
  finalSet
}
```

Fig. 3. R code of the createDescaledData function.

The function's input parameters: ***hci*** – netCDF identifier resulted on file opening, ***firstDate*** – date of the first data in the whole dataset, ***year*** – the desired year for which data descaling has to be made.

The **getBestInterval** function returns the first day index as day number inside a year which respects the imposed restrictions/thresholds for consecutive day (**Fig. 4**). In case of more suitable periods that with the highest average will be returned. The function's input parameters: ***dataVector*** – daily HCI data for a year for a single spatial location, ***minValue*** – minimum accepted HCI value for consecutive days, ***minAvgValue*** – minimum accepted HCI mean value for consecutive days, ***minLength*** – minimum length of consecutive days.

```
getBestInterval <- function(dataVector,minValue,
                            minAvgValue, minLength)
{
  dataVector[dataVector<minValue] <- 0
  maxAvg <- 0
  idx <- 0
  for(i in 1:(length(dataVector)-minLength))
  {
    values <- dataVector[i:(i+minLength-1)]
    if (sum(values==0,na.rm=TRUE)==0)
    {
      currentAvg <- mean(values,na.rm=TRUE)
      if (!is.na(currentAvg) & !is.nan(currentAvg))
       if (currentAvg > minAvgValue & maxAvg < currentAvg)
       {
         maxAvg <- currentAvg
         idx <- i
       }
    }}
  idx
}
```

Fig. 4 – R code of the getBestInterval function.

The **getBestforRaster** function creates the raster layer as a file for a given year considering the imposed thresholds (**Fig. 5**). The function's input parameters: ***hci*** - netCDF identifier resulted on file opening, ***firstDate*** – date of the first data in the whole dataset, ***minValue*** – minimum accepted HCI value for consecutive days, ***minAvgValue*** – minimum accepted HCI mean value for consecutive days, ***minLength*** – minimum length of consecutive days.

```
getBestforRaster <- function(hci,firstDate,year,
                              minValue,minAvgValue, minLength)
{
  dData <- createDescaleData(hci,firstDate,year)
  nc <- ncol(dData[,,1])
  nr <- nrow(dData[,,1])
  startIdx <- array(0,dim=c(nr,nc))
  for(i in 1:nr)
   {
    for(j in 1:nc)
      startIdx[i,j] <- getBestInterval(dData[i,j,],minValue,
                                       minAvgValue,minLength)
    }
  lon <- ncvar_get(hci,"lon")
  lat <- ncvar_get(hci,"lat")
  lyr <- raster(t(startIdx), xmn=min(lon), xmx=max(lon),
               ymn=min(lat), ymx=max(lat), crs="+proj=longlat")
  lyr <- flip(lyr)

  writeRaster(lyr,paste("HCI_",year,"_Min",minValue,"_Avg",
         minAvgValue,"_L",minLength,".tif",sep=""),overwrite=TRUE)
}
```

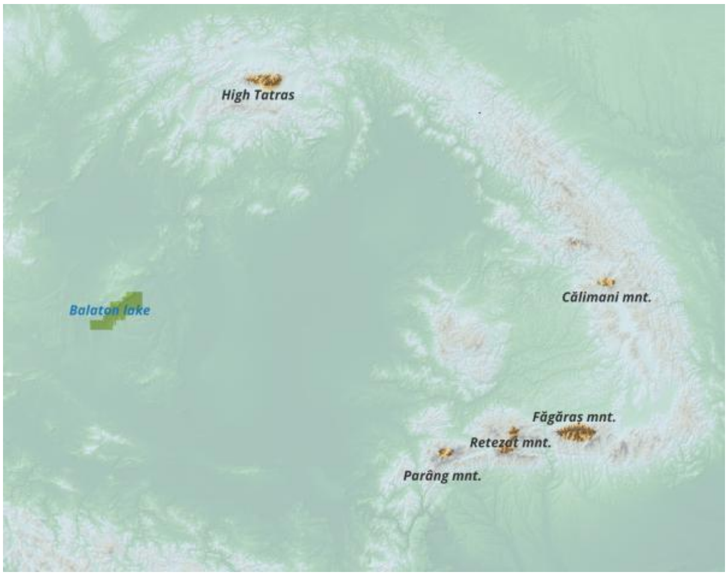
Fig. 5. R code of the getBestforRaster function.

In addition to the aforementioned functions, two others were defined to aid in automating data processing. The **getAllYears** function requires no parameters and is responsible for generating raster layers for every year. Subsequently, a new function was required to aggregate data for each location from all the raster layers containing the starting day of the most appropriate seven consecutive days. Data was aggregated using indices of central tendency, specifically the mean and median, along with two variations indices: standard deviation and interquartile range. The **createMaps** function was utilized, which compiles all files that correspond to the set pattern and within the designated time frame, to produce four raster layers displaying the mean, median, standard deviation and trend significancy for each location. Its parameters consist of two variables: ***limit***, which is the minimum HCI value utilized as the exclusive identifier for the files generated by the **getBestforRaster** function, and ***first*** and ***last***, denoting the index of the file set to be taken into account.

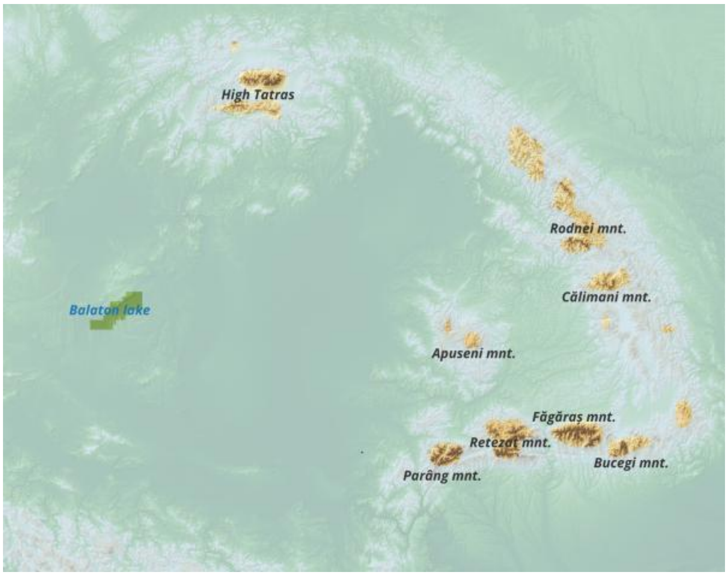
3. RESULTS AND DISCUSSION

The objective of the R software module development was to identify the optimal seven-day period in each calendar year. This is defined as the period in which the minimum HCI value for each day reaches or exceeds a predetermined threshold and with the highest overall average. Additionally, the mean value must also be at a minimum. Initially, we utilized two threshold pairs. For the first scenario (SCEN75), the acceptable minimum value for the consecutive day's HCI was 75, which lies in the mid-range of the "Very good" category. Additionally, the mean should be at least 85, which is also in the mid-range of the "Excellent" category. The second scenario (SCEN80) considers higher values, with a 5-point increase for the aforementioned thresholds. The minimum daily HCI is 80, while the minimum mean HCI is 90, which represents the lowest value in the "Ideal" category.

Throughout the entire 71 years period from 1970-2040, the mean HCI of SCEN75 shows that only the close neighborhoods of the highest mountains lacked appropriate periods. These locations are situated in High Tatras, Retezat, Parâng, Făgăraș and Călimani Mountains, all of which have peaks over 2000m (**Fig. 6a**). For SCEN80, additional areas beside the expanded locations of SCEN75 have been identified. These spots appear in the Apuseni Mountains as well as in the Rodnei or Bucegi Mountains and other locations with altitudes down to 1500-1600m (**Fig. 6b**). The areas that do not meet the desired criteria are 4.74 times larger than those for SCEN75. The study also included an analysis of two subperiods: the first spans 35 years between 1970-2004, while the second covers 36 years from 2005-2040. In both scenarios, the first subperiod reveals larger areas failing to reach minimum requirements. These findings suggest that more areas will become applicable for outdoor activities. A comparison of the ratio of these inadequately met areas between SCEN80 and SCEN75 shows 74% and 67%, respectively, in favor of the former.



a – SCEN75 scenario.



b – SCEN80 scenario.

Fig. 6. Regions which don't meet minimum scenario thresholds considering whole analysis period.

The percentage of the area gained is significantly lower when applying the highest HCI thresholds, implying an irregular increase in appropriate locations. The analysis undertaken for SCEN75 aimed to identify and examine the characteristics of the optimal seven-day periods. For each year, the most suitable seven-day periods were identified based on their starting day within the year. The resulting data series were then aggregated and analyzed for the entire period and the two sub-periods for each location. Based on the central tendency values of mean and median, it is clear that July and August are the most appropriate months for the entire analysis period (**Fig. 7**).

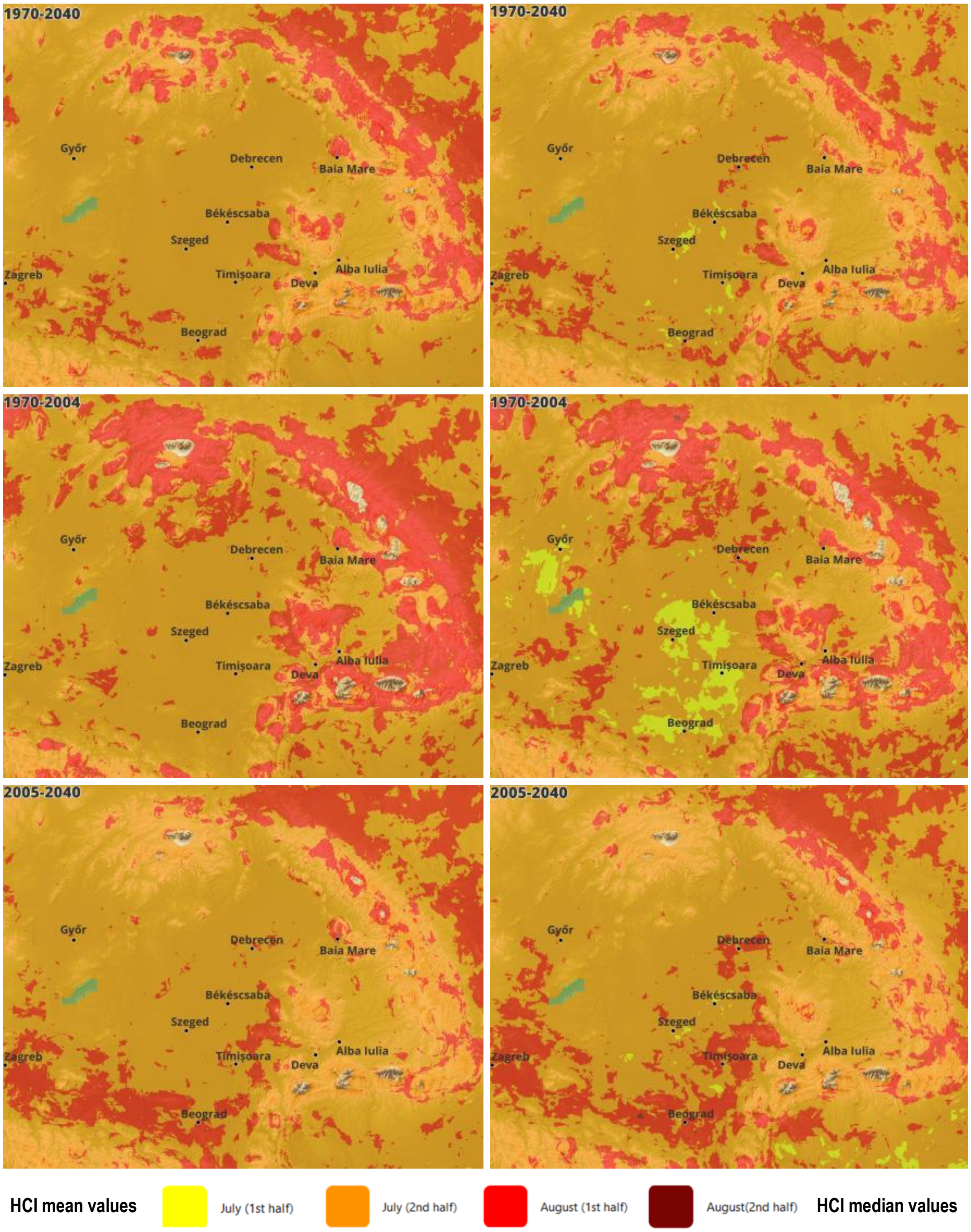


Fig. 7. Ideal seven-days period starting time

Specifically, for the mean value, only the latter half of July and early August are present. However, when considering the median value, the first half of July is also present in certain central-southern areas encompassing the Békéscsaba, Szeged, Timișoara, and Beograd regions. The first half of August is more prevalent in mountainous regions, whereas inside the Carpathian Basin, the second half of July is overwhelmingly preferred. After comparing the mean values of the two subperiods, it is clear that the most suitable period for future holidays starts in August, particularly in the Carpathian Mountains. However, for vast areas, the most suitable seven-day holiday starts in the second half of July instead of August. The first half of August is more beneficial in the southern part of the study area along the Zagreb-Beograd axis.

The median value reinforces previous findings, but with some refinements. In the first subperiod (1971-2004), the middle-south region and north Balaton Lake areas favoured the first half of July for outdoor tourism, while in the Győr region, the same period was optimal. However, in the second subperiod (2005-2040), these regions have shifted towards the second half of July or the first half of August. It is noteworthy that, for certain areas to the west and south of Belgrade, the optimal time for holidays has shifted to the latter half of August. The first few weeks of July are now only considered an ideal vacation period in a few isolated locations. Moreover, both the mean and median indicate a significant southern influx occurring in the first half of August along the Belgrade-Timișoara-Debrecen axis.

Changes between the two sub-periods are apparent, but they differ across different regions. In the southern, western, and central areas of the Carpathian Basin, the most appropriate period for outdoor tourist activities is delayed by 1-2 weeks. However, in the northern and eastern regions, the starting days' mean value is advanced by 1 week (**Fig. 8**). The same findings, but with pronounced values, are seen in the median values. Generally, two interlocking U shapes can be observed. The inverted U denotes regions where the ideal period is advanced, while the upright U indicates a delay in the ideal period.

The minor disparities between the mean and median values of the data series hint at noteworthy variations in the starting day across different years. Since the central tendency values are generic, collective values, the deviation inside the data series also holds significance. To this end, we computed the standard deviation and the interquartile range expressed in days for the entire period and the two subperiods.

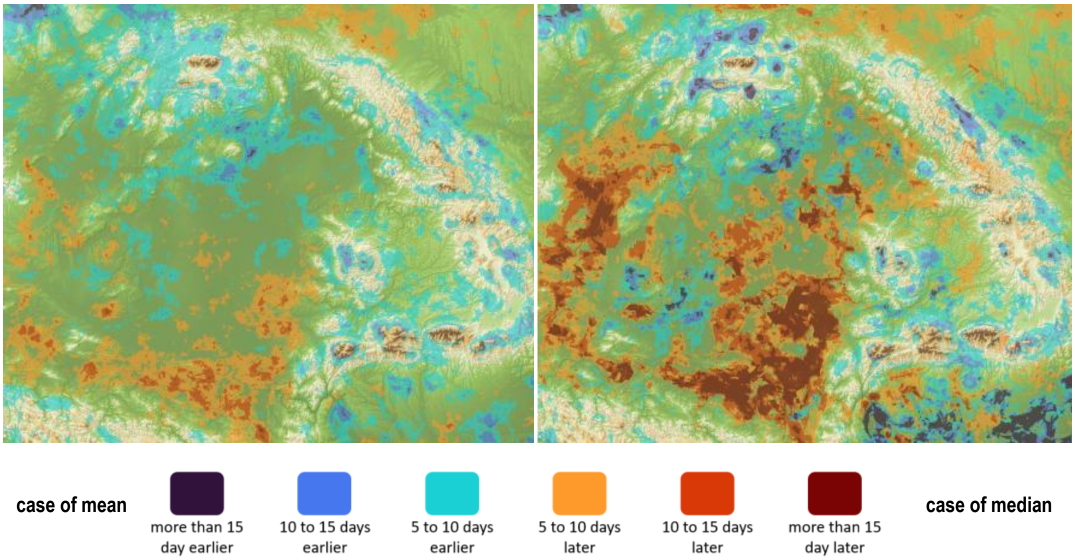


Fig. 8. Differences between 1970-2004 and 2005-2040 subperiods for the starting day for ideal seven-day holiday.

Both indices demonstrate a consistent pattern throughout the analysis period, with greater reduction in variation in the northern and eastern regions compared to the southern and western areas (**Fig. 9**). While a strong correlation exists between the two indices indicating internal deviation, an anomalous situation is evident during the first subperiod near Timişoara. Based on the standard deviation, a mid-value is recorded according to the legend. Additionally, the interquartile range shows that the dispersion of values falls within the low and very low categories.

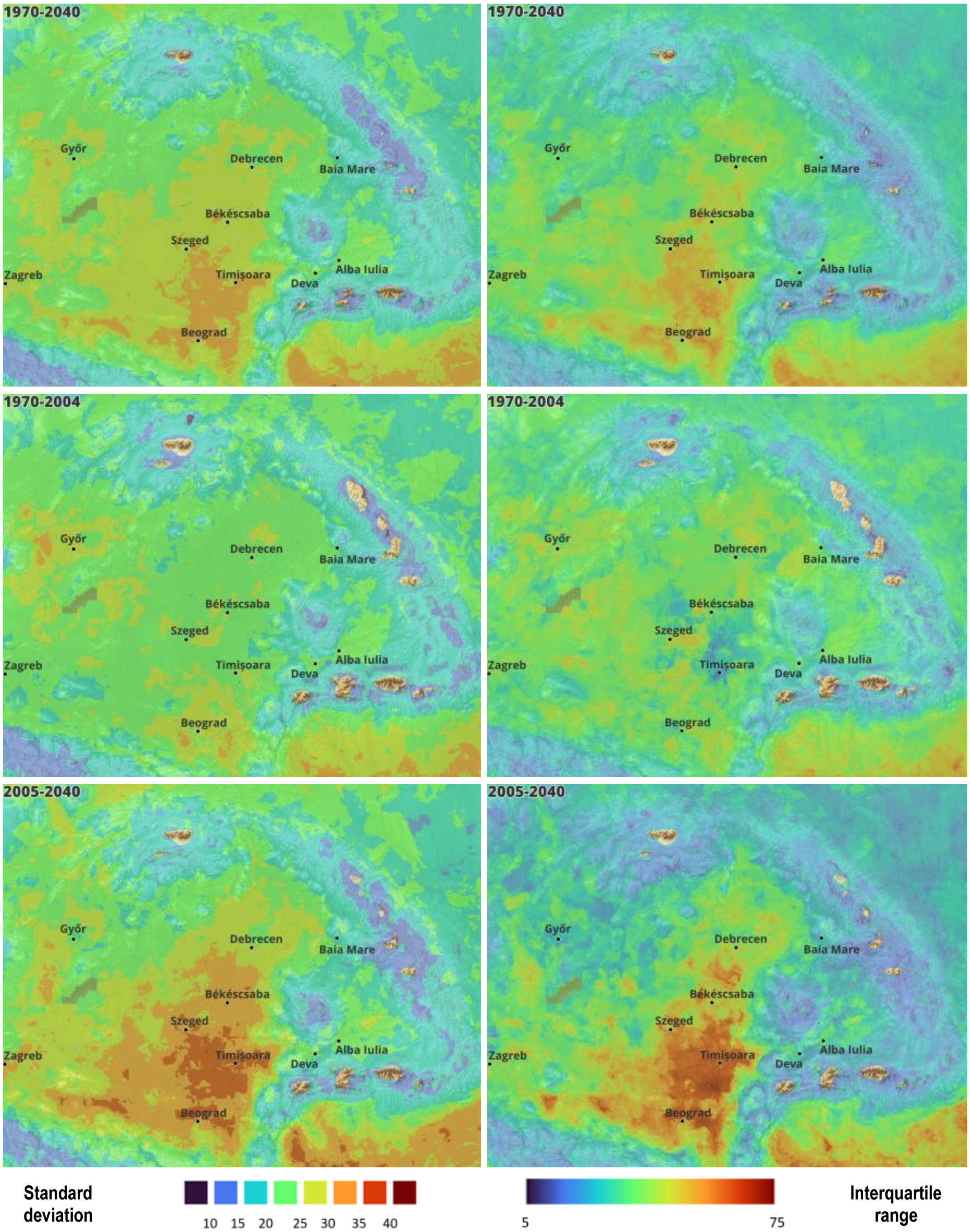


Fig. 9. Internal deviation of data series.

This indicates that around half of the values exhibit significant deviations in both directions, while for other locations, the distribution of values is more balanced, even if the values themselves are high.

Over the initial 35 years of the first subperiod, variations were less pronounced compared to those of the second subperiod. In the present and near future, it is improbable to generalize as to when it is worthwhile to commence holidays in the Beograd-Timișoara vicinity, given that deviations exceed a month. Upon assessing the stability of mean values, we conducted a trend analysis to determine the optimal starting day for each location.

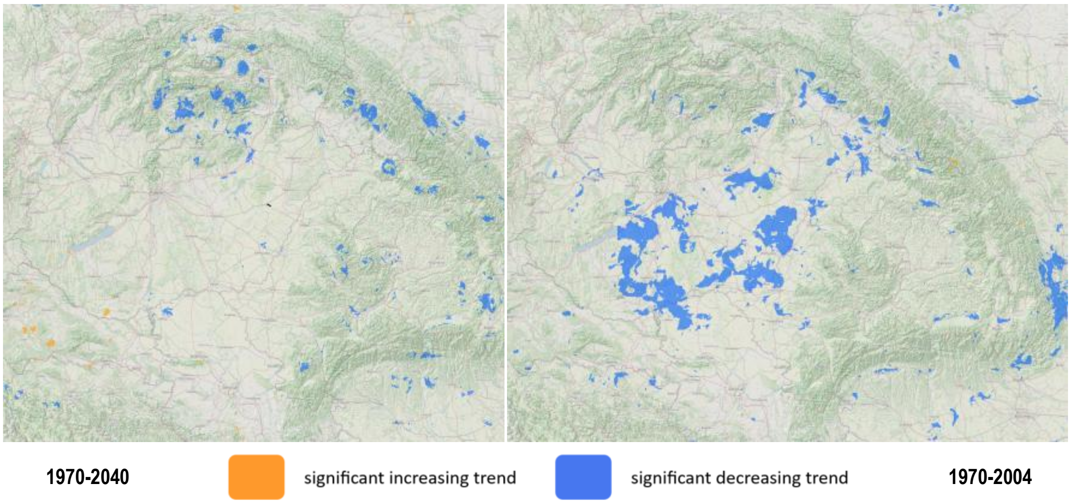


Fig. 10. Trends in ideal seven-day log holiday starting day.

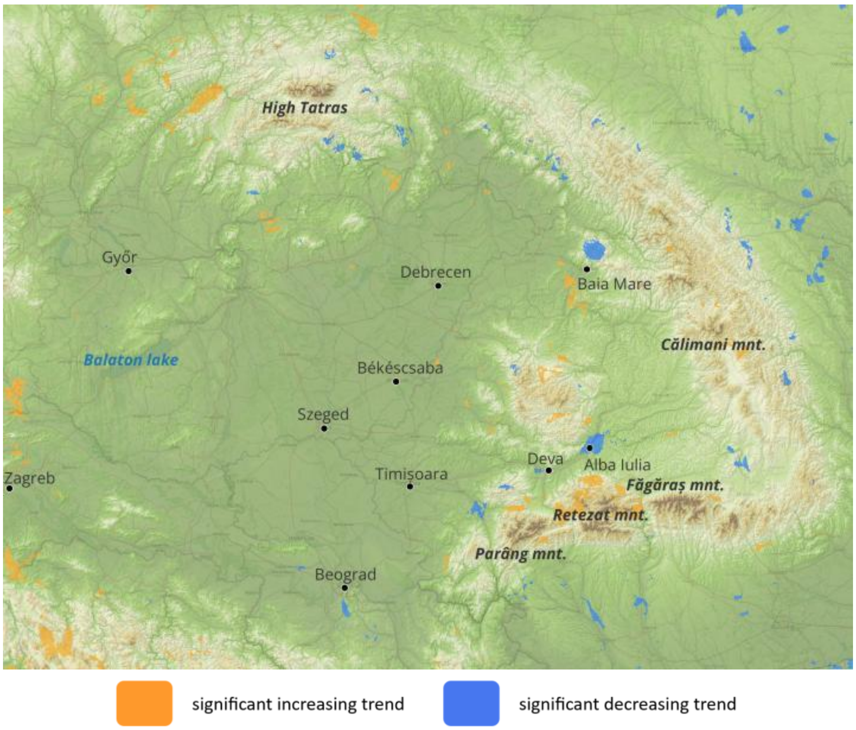


Fig. 11. Trends in ideal seven-day log holiday starting day for the 2005-2040 period.

While many locations do not exhibit a statistically significant trend in their data series values, other locations clearly do. The analysis of trend significance was based on the Mann-Kendall test (Fang et al., 2016).

Throughout the analysis period, it has been observed that there are certain locations displaying a significant decreasing trend. This suggests that the most favorable seven-day long period is moving earlier over the past 71 years (**Fig. 10**). These areas are mainly situated in the Carpathian Mountains. Additionally, an overall increasing trend can be noted to the east of Zagreb, indicating a consistent shift towards the end of the year in terms of the most desirable holiday period.

The two subperiods demonstrate significant differences in trends. During the first subperiod (1971-2004), decreasing trends were observed primarily in the interior territories of the Carpathian Basin. These areas became known for their early start to the ideal holiday season (**Fig. 10**). However, this trend is no longer evident in the second subperiod. Based on HCI values from the past 36 years, there are no clear trends present in the main part of the Carpathian Basin (**Fig. 11**). Although interesting situations can be observed locally, it is noteworthy that the northern areas of Baia-Mare exhibit a significant decreasing trend, while the southern areas show an increasing trend. Furthermore, Alba Iulia and Deva, both towns with high tourist potential, experience a significant decreasing trend in the starting day of the ideal tourist period. Conversely, important areas over the valley in the Retezat Mountains exhibit an increasing trend.

4. CONCLUSIONS

Climate change affects many aspects of everyday life, including recreational activities. Our study examined how the Holiday Climate Index (HCI), developed specifically for urban and nature-based tourism, will evolve based on the EC-EARTH climate model for the Carpathian Basin. We have also developed a parametrizable R software module for data processing to support further similar investigations. Our research is focused on identifying the optimal seven-day period of each year where the HCI index exceeds a certain threshold, considering both the minimum and mean values. For this study, the minimum value was set at 75 (denoting a very good rating), while the mean was set at 85 (indicating an excellent rating).

The results obtained cover three distinct aspects. Firstly, it has been determined that there are areas within high mountainous regions that fail to meet the imposed requirements. These locations are therefore unsuitable to be utilized as tourist destinations for a minimum of seven consecutive days.

Secondly, by examining historical data between 1970 and 2004 as well as modelled data from 2005 to 2040, we have compared past and forecasted future trends according to two sub-periods. Based on the mean and median values, the most suitable time to begin a seven-day holiday appears to be during the latter half of July. This trend is consistent even in mountainous areas where the optimal starting day was previously in the first half of August during the first subperiod. Furthermore, a new development is the occurrence of the first half of August being the optimal starting time in mid-southern locations, which was previously the first half of July during the first subperiod.

Finally, the trend analysis indicates that the previous noteworthy decline in the central area of the Carpathian Basin has ceased, and distinct significant trends emerge in the peripheral regions. These differing trends may or may not be linked to altitude, and though they are in close proximity to each other, they have the potential to coexist in several square kilometers.

All of the above findings show how climate change impacts outdoor recreational activities, indicating that it will become increasingly difficult to determine the best time to plan a holiday based on ideal weather conditions.

ACKNOWLEDGMENT

The presented research was supported by the DOMUS scholarship program of the Hungarian Academy of Sciences.

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