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The Analysis of the Long-Term Changes of the Growing Seasons in Kyiv, Ukraine Using Global Historical Climatology Network-Daily Database

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SUMMARY

The objective of this study was to evaluate the long-term changes in the timing of the growing season (GS) parameters for the city of Kyiv for 1881-2020 using daily mean temperatures for three thresholds (5, 10 and 15°C). Registered changes in the GS parameters tend to persist across all time periods except 1961-1990 during which trends are usually insignificant or have opposite direction comparing to the other intervals. The GS tend to become longer, but the mechanism of this elongation varies among the seasons. For the long GS a shift towards earlier start is responsible for the increase in the length, while for the summer GS the elongation reveals itself through the delays in the end of the season. The most prominent changes describe the active GS which, according to the results of the analysis, tends to both an earlier start and a later end. Changes in the start of the GS are more rapid than changes in the end, for example, decline of 1 day per 1.7 years versus increase of 1 day per 1.9 years for the modern standard normal period.

Introduction

In the colder environments growing season (GS) changes (*IPCC, 2021*), but there is a lack of the assessments of magnitude and direction of these changes for the city of Kyiv. The precise assessments based on long-term observations are necessary to make sound prognoses and to develop data-driven climate change adaptation and greening strategies.

The primary objective of this study was to evaluate the long-term changes in the timing of the GS parameters for the city of Kyiv for 1881-2020 using daily mean temperatures for three thresholds (5, 10, and 15°C). The specific objectives of this study were (1) to develop data preprocessing approach to define GS parameters using Global Historical Climatology Network data; (2) to model changes in the timing of the GS using different linear trend estimators; (3) to assess changes in the timing of GS for the time periods of 1881-2020, 1961-2020, 1961-1990, 1991-2020.

Data and Methods

Long-term changes in the GS were analysed using Global Historical Climatology Network – Daily climate summaries for the station of Kyiv – Zhuliany International Airport (WMO ID 33345) (*Menne et al., 2012*). The dataset contains daily values on precipitation, snow depth, minimum, maximum, and average temperature, as well as additional flags of source, measurement, and quality of each variable. Data entries are available for the period of record from January 01, 1881 up to present with the overall data completeness 99%.

Data processing was performed in R 4.1 environment (*R Core Team, 2021*) using libraries tidyverse (*Wickham et al., 2019*), lubridate (*Grolemund and Wickham, 2011*), modern (*Skinnider, 2020*), and zoo (*Zeileis and Grothendieck, 2005*)[1]. Average temperature parameter and its attributes for the 140-years period from 01.01.1881 to 31.12.2020 were selected for the analysis. According to the data quality flag the parameter has no entries that failed any quality assurance check. In addition, average temperature series were tested for the presence of outliers using the modified Z score method of Iglewicz and Hoaglin (*Iglewicz and Hoaglin, 1993*).

Vegetation periods can be defined as the largest number of consecutive days with the daily mean temperature equal to or above 5°C (long vegetation period), 10°C (active vegetation period), and 15°C (summer vegetation period). The parameters of start (recorded as day of year), end (day of year), and length (days) describe each vegetation period. To define correctly the longest period, the data should not contain any missing values which induce gaps for the periods of interest. The data was tested for the presence of over-5-days gaps during the provisional vegetation period of March-October (*World Meteorological Organization, 2017*). Five years satisfied the criterion (1941, 1943, 2007-2009) and were excluded from the further analysis. Data gaps shorter than 5 days were replaced by linear interpolation. Finally, the preprocessed data for 135 years were used to define the start, end, and length parameters of the long, active, and summer vegetation periods of each year.

Long-term trends in vegetation periods parameters were analyzed and compared for the time periods as follows:

- 01.01.1881-31.12.2020 – all available data record from the very beginning of observations to the end of the latest climatological standard normal period.
- 01.01.1961-31.12.2020 – data record available for two recent climatological standard normal periods.
- 01.01.1961-31.12.1990 – the first climatological standard normal period often used as a benchmark against which recent observations are compared.

[1] Scripts and results of the analysis are available via the repository https://github.com/darsvid/rp_2021_uhi_kyiv

- 01.01.1991-31.12.2020 – recent climatological standard normal period often used to describe modern climate.

The parameters of vegetation seasons were tested for the presence of linear trends during each time period using the estimators of ordinary least squares (OLS), Theil-Sen single median (TS) (*Theil, 1950; Sen, 1968*), and Siegel repeated medians (SM) (*Siegel, 1982*). Compared to OLS, both TS and SM estimators are non-parametric methods robust against data skewness, heteroscedasticity, and outliers with the tolerance for up to 29% and 50% of arbitrary corrupted data respectively. As proven robust estimators of trend magnitude and direction, TS and SM slopes have been successfully applied to define various aspects of dynamics (*Svidzinska, Korohoda 2020; Svidzinska 2021*).

Results

Table 1 summarizes the results of the long-term trends analysis. Registered estimators confirm the presence of significant long-term changes, but their direction and magnitude vary across parameters, GS, and time periods.

Table 1 Observed long-term changes (days per year) in the parameters of growing seasons[2]

	T≥5°C			T≥10°C			T≥15°C		
	Ordinary least squares	Theil-Sen single median	Siegel repeated medians	Ordinary least squares	Theil-Sen single median	Siegel repeated medians	Ordinary least squares	Theil-Sen single median	Siegel repeated medians
				start of growing season					
1981-2020	−0.07**	**−0.07*****	−0.07***	−0.12***	**−0.13*****	−0.12***	0.02	0.03*	0.02
1961-2020	−0.07	−0.08*	−0.11*	−0.22**	**−0.22*****	−0.19**	0.03	0.05	−0.01
1961-1990	0.24	0.31**	**0.40****	0.02	0.00	0.06	0.42	0.86**	1.29
1991-2020	−0.26	−0.24*	−0.17	−0.45	**−0.60*****	−0.90**	−0.11	−0.21	−0.36
				end of growing season					
1981-2020	0.05*	0.04***	0.05	0.08***	**0.07*****	0.05***	0.13**	**0.14*****	0.14***
1961-2020	0.07	0.00*	−0.01	0.19*	**0.18*****	0.12***	0.25	**0.22*****	0.23**
1961-1990	0.11	0.09	0.17	0.23	0.13*	0.22*	−0.22	−0.06	−0.15
1991-2020	0.26	0.17**	−0.01	0.55**	**0.52*****	0.59***	0.17	0.40	0.41
				length of growing season					
1981-2020	0.12***	**0.12*****	0.10***	0.20***	**0.20*****	0.16***	0.11*	**0.11*****	0.10***
1961-2020	0.15	**0.14*****	0.15**	0.41**	**0.42*****	0.33***	0.21	0.22***	0.28*
1961-1990	−0.12	−0.07	0.03	0.21	0.33	0.29	−0.64	**−0.60*****	−0.86**
1991-2020	0.53	**0.50*****	0.58**	1.00**	**0.93*****	1.31***	0.28	0.31	0.04

[2] *Marginally significant ($0.01 < p \leq 0.05$); **significant ($0.001 < p \leq 0.01$); ***highly significant ($p \leq 0.001$). Numbers highlighted in **bold** have highest significance (minimum *p*-value).

Significant changes in the start are registered for the long and active GS (Table 1). For overall period of observations there is a highly significant downtrend which means the GS shift to an earlier start. Consistent changes across all time periods, except 1961-1990, are registered for the active GS. The most rapid change of 1 day per 1.7 years describes the modern climate period. There are no any significant changes for the start day of the summer GS.

Significant changes in the end are registered for the active and summer GS (Table 1). For overall period of observations there is a highly significant upward trend which means the GS shift to a later end. Consistent changes across all time periods, except 1961-1990, are registered for the active GS. The most rapid change of 1 day per 1.9 years describes the modern climate period. For the start day of the summer GS significant changes are registered for longer periods of observations with the rate of change 1 day per 4.5 years for the period of 1961-2020.

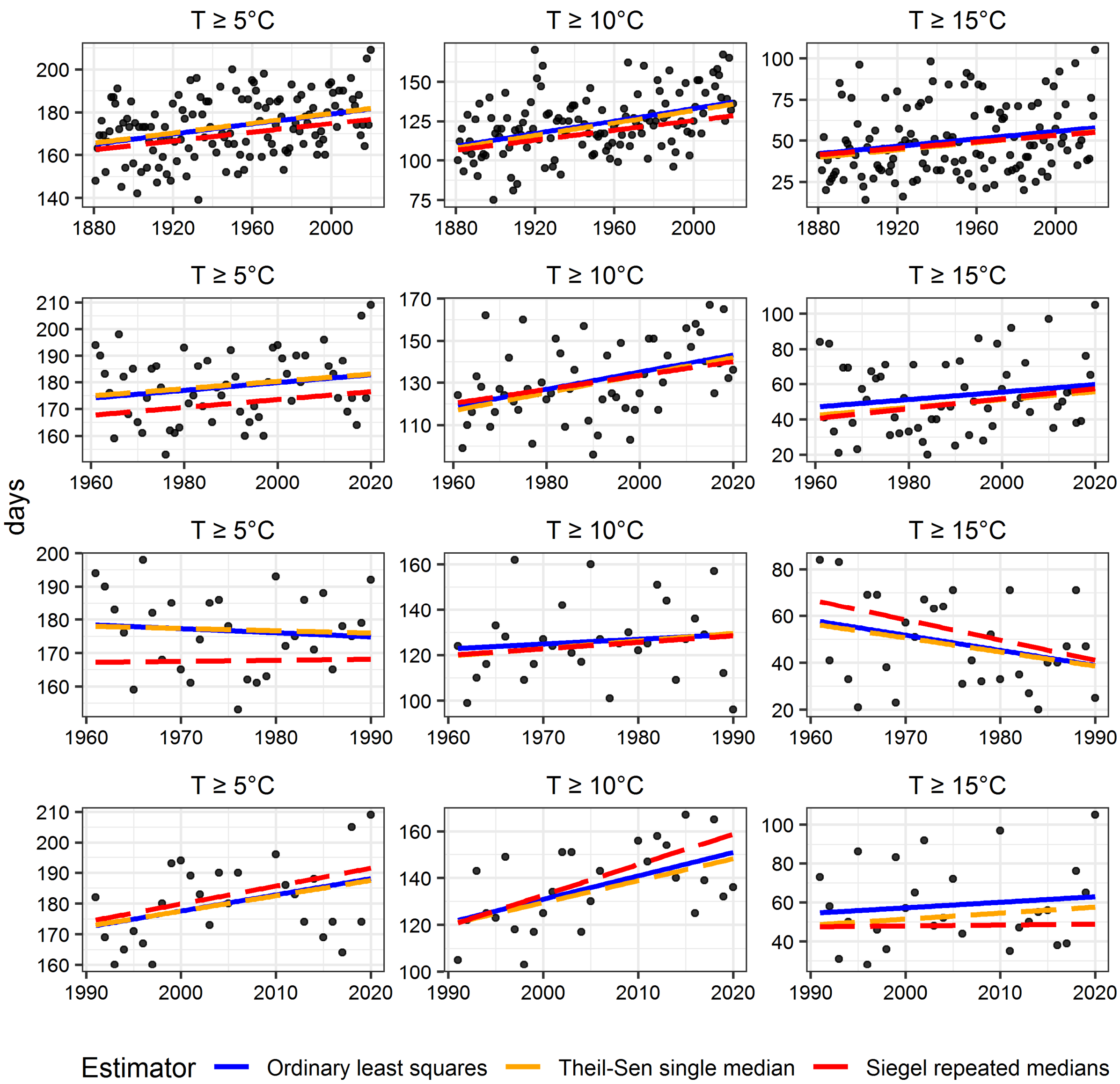

***Figure 1** Long-term dynamics of the length of growing seasons.*

Significant changes in the length are registered for the long and active GS (Table 1, Fig. 1). For overall period of observations there is a highly significant upward trend which means the GS tend to become longer. Consistent changes across all time periods, except 1961-1990, are registered for the long and active GS. The most rapid change of 1 day per 1.1 years describes modern climate period of the active GS. For the length of the summer GS significant changes are registered for the overall period of observations with the rate of change 1 day per 9.1 years.

Conclusions

Registered changes in the parameters tend to persist across all time periods except 1961-1990 during which trends are usually insignificant or have opposite direction comparing to the other intervals. The GS tend to become longer, but the mechanism of this elongation varies among the seasons. For the long GS a shift towards earlier start is responsible for the increase in the length, while for the summer GS the elongation reveals itself through the delays in the end of the season. The most prominent changes describe the active GS which, according to the results of the analysis, tends to both an earlier start and a later end. Changes in the start of the GS are more rapid than changes in the end, for example, decline of 1 day per 1.7 years versus increase of 1 day per 1.9 years for the modern standard normal period.

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