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Trends in thermal growing season length from years 1955–2020 — A case study in hemiboreal forest in Estonia

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We present the change in the thermal growing season based on a unique long-term climatological data set obtained at the Järvselja Training and Experimental Forestry Centre in southeast Estonia. The data cover the years 1955–2020 and we employed the growing degree-days (GDD) algorithm on them. We defined the days when temperature is persistently above 5°C as GDD5; when above 10°C as GDD10. Our results showed that both GDD5 and GDD10 have increased by 14.8 (2.2 days/decade) and 18 (2.8 days/decade) days, respectively. The recent average growing season length is 204 days in case of GDD5 and 164 days in case of GDD10. Our results reveal that during the most recent decade, the length is stagnating and the onset in spring delays while the growing season's end extends towards winter. We find that the number of extreme cold (below –20°C) dropped by a factor of 3.3 while extreme warm days (above +25°C) rose by a factor of 2.6. Possible implications of these changes on the forest ecosystem are discussed.

Introduction

The growing season length has a massive effect on forest ecosystem function (White *et al.* 1999, Metslaid *et al.* 2018). Higher temperatures accelerate bud break (BB), flowering and stem elongation in the spring, as well as thermal growing season, which can increase growth and productivity (Gunderson *et al.* 2012). Keeling *et al.* (1996) and Myneni *et al.* (1997) found that due to an earlier start of the spring in northern latitudes, forest productivity increases. However, there is also evidence that the earlier onset of vegetation growth and possible carbon gain during spring is cancelled out by a warmer summer temperature and a longer frost-free period that allows higher and longer release of carbon from ecosystem respiration (Nemani *et al.* 2003). Global climate warming, characterised by increased greenhouse gas levels and increase in annual mean temperature have major effects on boreal and hemi-boreal forests, leading to an expansion of the growing season and to changes in photosynthetic activity (Hari and Kulmala, 2008). The global average surface temperature has increased due to human activities, which were estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C (IPCC 2021). Global warming is likely to reach 1.5°C between 2030 and 2052 if

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it continues to increase at the current rate (IPCC 2021). In Estonia, air temperature has increased by 1.0–1.7°C during the second half of the 20th century according to different meteorological stations all over Estonia (Jaagus 2006, Jaagus *et al.* 2017). Menzel *et al.* (2001) analysed phenological changes in the growing season in Germany using more than four decades (1951–1996) of data and found clear advances in the key indicators of shift towards early spring (–0.18 to –0.23 days/year). They further report on notable advances in the succeeding spring phenophases like leaf unfolding of deciduous trees (–0.16 to –0.08 days/year). However, phenological changes were less strong during autumn (delayed by +0.03 to +0.10 days/year on average). In general, the growing season has been getting longer by 0.2 days/year, where in average in 1974–1996 the growing season was up to five days longer than in the 1951–1973 period. In a study by Sparks *et al.* (2005), it was reported for UK Sussex that from 1980 to 2000, 25 out of 29 springs came earlier in 1990–2000 than in 1980–1989. The average advancement from 1990–2000 was 5.5 days. During the last century, on average, the winter and spring temperatures have increased and datasets showed earlier development in spring flowering (Beaubien and Freeland 2000). In a study made in Latvia and Lithuania, changes in air temperature and precipitation for the 1971–2000 period showed similar trends like the study made in the UK. A trend analysis of spring (March–May) temperature changes demonstrated statistically significant increases for all the stations (Mann-Kendall test > 1.92). At the same time, examining monthly temperature data showed significant increases only in April (Mann-Kendall > 1.97) (Kalvane *et al.* 2009). Ecosystems in boreal and temperate regions may show a higher sensitivity to temperature changes compared for instance to dryland, temperate or tropical systems (Heyder *et al.* 2011).

On a regional scale, there is evidence on a temperature rise in the Baltic Sea basin and on an increase in the annual temperature of 1.5 to 2°C within the last three decades is reported (The BACC II Author Team, 2015). According to Jaagus *et al.* (2017), the most significant rise in temperature in Estonia occurs during the winter and spring months. This is in line with several studies based on phenological, satellite and climatological data (Sparks and Carey 1995, Ahas 1999, Sparks *et al.* 2005, Wolfe *et al.* 2005) that showed shifts in timing of the beginning and ending, and an increasing length of the growing season (see Table S1 in Supplementary Information). For instance, in Estonia, the growing season in the years 1965–2013 lasted, on average, from April 22 to October 28. The evidence points to a lengthening of the growing season of ca. 10–20 days in the last few decades, where an earlier onset of the start is most prominent (Linderholm 2006, Linderholm *et al.* 2008). Ahas (1999) reported that Estonian springs have lengthened for 8 days on average over the 80-year study period, and that during the 40-year period from 1952 to 1996, spring has warmed even faster. Even more, it turned out that spring was advancing about two times more rapidly in the coastal regions due to less sea ice cover of the Baltic Sea, which usually causes the spring to arrive later in the coastal region than in the inland areas.

According to Carter (1998), Ahas (1999) and Linderholm (2006), the thermal growing season is the entire period when plants are able to grow in theory. It is important to differentiate the term growing season from the term growing period, because the last one is the period when actual growth takes place (Linderholm 2006, 2008). The thermal growing season can be defined as the period when daily average temperature is higher than 5°C for 5 consecutive days.

In this study, we present for the first time results of an analysis of 65-year thermal growing season developments based on recorded temperature time series in a hemiboreal forest ecosystem at the Järvselja Experimental Forestry Centre in southeast Estonia. We assessed the trends of the thermal growing season and occurrences of extreme cold and warm days. We hypothesize that based on long-term daily temperature recordings with different sample protocols, the growing season length in Järvselja follows the changes in the regional trends. We further hypothesize that the sampling method does not introduce a bias to the daily averaged temperatures used to determine the length of the thermal growing season.

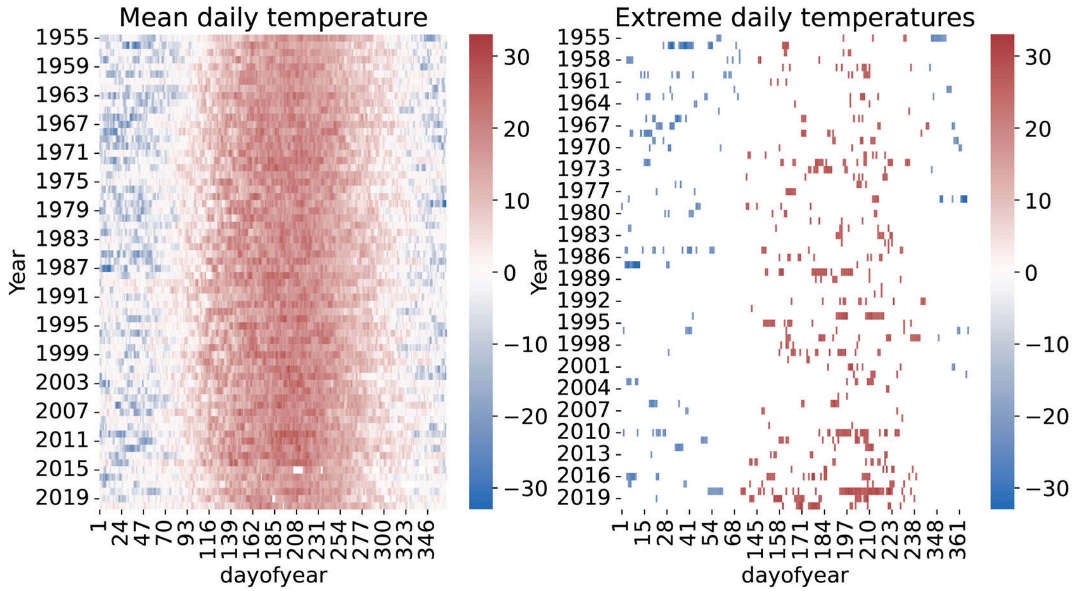

Fig. 1. Daily mean and extreme temperatures in °C recorded at the Järvselja Experimental Forestry Centre from 1955 to 2020. The temperature extremes show the days per year where the temperatures fell below –20°C or rose above 25°C.

Material and methods

Site description and data collection

The temperature data we used for this paper cover the period from 1955 to 2020 (Fig. 1). All data were obtained at the Järvselja Experimental Forestry Centre in southeast Estonia. The Centre is located in the close vicinity of Lake Peipus. According to the climatic description (Ahas 1999), Järvselja is located in the hemiboreal zone and is characterised by mixed forests. The dominant tree species are silver birch (*Betula pendula*) and downy birch (*Betula pubescens*), Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), common aspen (*Populus tremula*), black and grey alder (*Alnus glutinosa, Alnus alba*). The mean annual temperature in the area varies between 4°C and 6°C, and the mean annual precipitation is 500–750 mm with about 40–80 mm as snow (Noe *et al.* 2015).

Over time, changes in the measurement equipment, place, but also in the method occurred. From 1955 to 2014, the temperature measurements were taken at the meteorological observation station in the small village of Järvselja where the Forestry stations headquarter is located. Since 2015, we used the fully automated measurement system of the Station for Measuring Ecosystem-Atmosphere Relations (SMEAR), which is located one km north of Järvselja Forestry station.

At the Järvselja forestry station, weather observations have been conducted since 1922 and digitalised data are available since 1955. Three times a day, at 9:00, 15:00 and 21:00, the meteorological data were recorded using a recording minimal-maximal thermometer, aka Six's thermometer. This type of temperature recording "memorises" the minimal and maximal temperature that occurred during the recent period and it was reset at the next reading time. By that, the measurements consisted of one nighttime and two daytime, morning and afternoon, data points, each employing the minimal and maximal temperature over that period. Alongside temperature a set of weather characteristics, such as cloudiness, wind direction, visibility, precipitation, etc., were recorded. While this method does not allow to trace back the exact time when a maximum or minimum occurred, it allows to calculate for each period an average temperature and a daily mean, maximal and minimal temperature. Starting from the year 2001 until 2014,

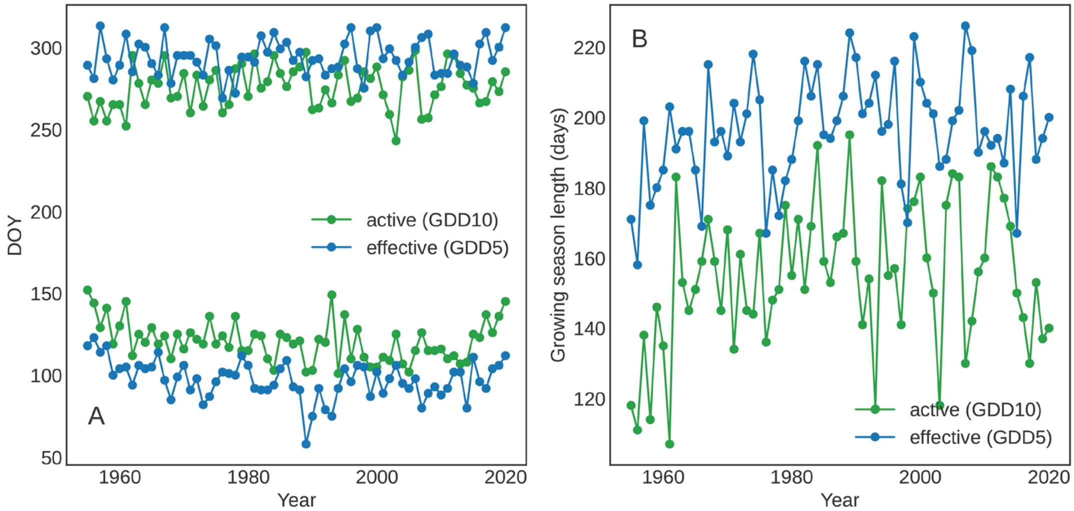

Fig. 2. Changes in the growing season from 1955 to 2020. In (**a**), we show the shift of the start and end days (DOY) of the thermal growing season in Järvselja. In (**b**) we show the change in the length of the thermal growing season. In both cases, GDD5 (> 5°C) and GDD10 (> 10°C) the positive trend is clearly visible ($p < 0.05$ for both). According to Mann-Kendall test GDD5 and GDD10 lengths have shown increasing trends (h_0 = true and $p < 0.05$).

the measurement protocol was changed and the daily mean temperature was recorded. Since 2014, fully automated meteorological measurements (Vaisala WXT520 Weather transmitter, Vaisala, Finland) were conducted at the SMEAR Estonia station with a recording frequency of 10 minutes. Data were processed every half an hour, and daily minimum, maximum and mean temperatures were stored. To assess the influence of the change in the measurement protocol over time we simulated the three different protocols using the 10-minute frequency data from 2014 to 2020 (see supplemental material). Essentially, the cross correlation between the simulated temperature time series per protocol ranged between 0.94 and 1, indicating that the choice of a certain measurement protocol does not introduce a bias between them.

As a final step, we compiled a time series that covers the years from 1955 until 2020 with daily maximum, minimum and averaged temperatures. We further defined two criteria to denote extreme temperatures. Given the averaged maximal and minimal temperatures (Estonian climate normals, https://www.ilmateenistus.ee/kliima/kliimanormid/ohutemperatuur/?lang=en), we defined temperatures lower than –20°C as extreme cold and temperatures above 25°C as extreme warm, in order to assess changes in the frequency of these events over the 65 years in focus (Fig. 2).

While preparing the temperature data, we checked the input data quality and data coverage. Overall, the final, daily-averaged input data covered 99.8% of days in the period from 1955 to 2020. The longest gap in the data was detected in November 2017, when in total 11 days in a row were lacking due to data storage system malfunction. Our data set follows and fulfils the US EPA technical requirements (US EPA, 2021) to calculate the growing-degree-day (GDD) indicator. To qualify, a data set need to comply to at least one day per month with a maximum and minimum temperature and a maximum data gap of not more than 30 consecutive days, and at least 95% of data coverage over the full period assessed (US EPA, 2021).

Data analysis

The general workflow was to apply the GDD algorithm (US EPA 2021), described in the next sub-section, to identify the days when the temperature remains persistently above 5°C, which is defined in agrometeorology as the effective thermal growing season (Peltonen-Sainio *et al.* 2009), and the days when the temperature is persistently above 10°C, denoting the active thermal growing season. We further use GDD5 for the growing season length with growing-degree-days above 5°C, and GDD10 for the growing season with growing-degree-days above 10°C (US EPA 2021). That step generates two new time series for GDD5 and GDD10 thermal growing seasons that contain the day-of-year (DOY), the start date, end date, and the length of the season.

In the second step, we set up linear and logarithmic models of the thermal growing season length and applied the Mann-Kendall trend test for both GDD5 and GDD10 thermal growing seasons data.

The third step was to use five-year binned data to test the asymptotic behaviour of the thermal growing season's dynamic that cannot grow unlimited, and the fourth step was to apply the linear model and Mann-Kendall trend test to the change on the extreme cold and warm day data over the whole period of 65 years.

All the data processing was done using Python ver. 3.10 (Van Rossum and Drake 2009), together with the *pandas data analysis manipulation* library (Reback *et al.* 2022). All the statistical modelling was done using the *statsmodels* Python package (Seabold and Perktold 2010) and Mann-Kendall testing by the *pymankendall* package (Hussain and Mahmud 2019). All the models were fitted using the ordinary least square (OLS) method. The level of significance for the *t*-test in parameter estimation was set to 0.05, and normality of residuals was tested using Jarque-Bera test with a significance level of 0.05.

Growing season selection algorithm

Selecting the beginning and end of the thermal growing season is not a straightforward task. While the obvious way to determine these days by searching for the occurrence of a threshold temperature in spring and autumn already poses the difficulty in finding either the first or last occurrence consistently. Searching from winter to summer will in most cases not retrieve the same day as searching in reversed order from summer to winter. These days will in most cases be different and large biases are likely to occur just by choosing a search direction. Therefore, we adopted the concept of growing-degree-day (GDD), which has been used on temperature data (Linderholm 2006) or phenological data, such as pollen (Zhang *et al.* 2015). Similar concepts of temperature sums over time have been successfully applied in seasonal models of tree photosynthesis (Hari *et al.* 2017, Kulmala *et al.* 2019) over a range of ecosystems.

The growing season's start is then defined as the period when the daily average temperature does not fall below 5°C or 10°C for more than five consecutive days. It ends, when the daily average temperature falls again below 10°C or 5°C for more than five consecutive days (Linderholm, 2006, Tarand *et al.* 2013).

The growing-degree-day is defined as the integral over a time interval:

$$\mathrm{GDD} = \int (T(t) - T_b)\, dt\ . \qquad (1)$$

Here, T is the temperature, and the threshold temperature, T_b, was set in our case to either 5°C or to 10°C for GDD5 or GDD10. Since we are using discrete time steps of one day, Eq. 1 can be rewritten as:

$$\mathrm{GDD} = \textstyle\sum_{i=n}^{m} (T_i - T_b), \qquad (2)$$

for a series of n days. Here, GDD ≥ 0 if $T_i \geq T_b$.

Our implementation of the search algorithm needs therefore to find the DOY from which on GDD ≥ 0 to determine the start of the growing season. To determine the end of the growing season, we need to find the DOY for which GDD < 0 is valid. We are splitting the dataset into two parts, a spring part covering DOY 1 to DOY 182 and an autumn part covering DOY 356 or 366 to DOY 182. Reversing the order of the autumn dataset allows us to optimise the search algorithm in such a way that we can use only one criterion because searching for the value when GDD < 0 occurs is similar to search GDD ≥ 0 on the reversed dataset. Once the list of DOYs per dataset has been created, we test persistency by applying Eq. 2 on the temperatures

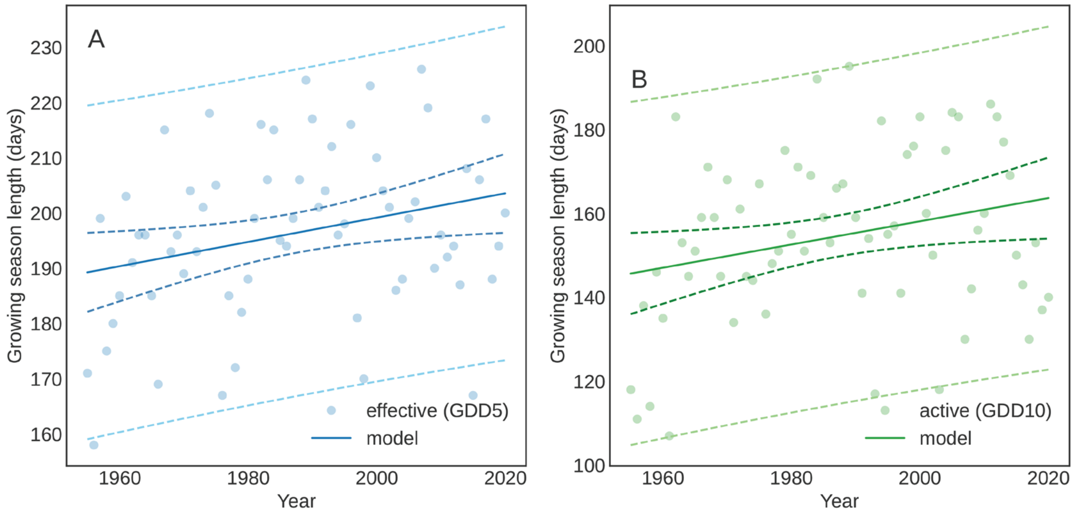

Fig. 3. Results of the linear model for (**a**) GDD5 and (**b**) GDD10. In both cases, the darker dashed lines describe the confidence interval for the trend and the lighter dashed lines for a new observation.

where the index, n, is set to the first DOY in the list and m to the next one. Please note that the distance between two subsequent DOYs in the list is always equal or larger than one. In the case that GDD is negative, the next two DOY entries are taken from the list. Once a positive GDD is reached, the lower DOY is set as the day when the growing season is starting in spring or ending in the case of the autumn data set.

Estonian weather service network data

To set the growing season changes measured in Järvselja into perspective with available Estonian data, we applied data on GDD5 provided by the Estonian Environmental Board. Data from 11 stations were used for this analysis (Fig. S1 in Supplementary Information). From this dataset, we included all stations data that had the same temporal coverage. The data contains the start and end of the growing season per year. For each station, including Järvselja, the linear relationship between the thermal growing season length and the year was assessed by a linear regression. The parameter that determines the change in growing season was used to test the significance of the trend according to the time series data.

Results

We found that in Järvselja, both GDD5 and GDD10 growing season's lengths increased from 1955 to 2020 (Fig. 2) by approximately half a month, 14.3 days for GDD5 and 18 days for GDD10. The year-to-year fluctuations in the growing season lengths were rather large, and therefore we tested two modelling approaches; a linear case as the simplest approach to describe the positive trend in the data, and a logarithmic approach. The latter was to assess whether the length of the growing season levels off in spring and autumn when solar radiation is limited by the short days at the latitude of the measurements. We found no difference between the linear and the logarithmic models, as R^2, F-test and AIC (Akaike's criterion) had the same results, and therefore we decided to use the simpler linear model on the year-to-year based data. We estimated for GDD5 an elongation of about 2.2 days per decade and for GDD10 of about 2.8 days per decade (Fig. 3a and b), and all the model parameters were significant with $p < 0.05$. From our results, we can say that the current GDD5 in Järvselja is in the range from 196 to 211 days with a mean of 204 days. Because of high fluctuations between the different years, the range for a new sample taken is even wider and spans from 173 to 234 days. In the case of

GDD10, we found an average length of 164 days spanning between 147 and 173 days, and a new sample may be found in the range between 122 and 205 days. The results of the Mann-Kendall trend test gave results in a similar range, and GDD5 and GDD10 enlarged by 2.1 and 3.1 days per decade, respectively, both with $p < 0.05$. In general, GDD5 had higher year-to-year fluctuations than GDD10 (Fig 2b). The change in the growing season is clearly seen in Fig. 2a and b, and the shift to an earlier onset of the vegetation period in spring is more strongly expressed than the delay in the autumn. Linderholm *et al.* (2008) revealed comparable trends while studying thermal growing season trends in the Greater Baltic area using 49 stations and daily mean temperatures. They found that from the period 1951–2000, the growing season length increased by 7.4 days over all the area covered, while for the stations located in Estonia only, Vilsandi and Võru, the increase was 12.2 and 11.5 days, respectively. Linderholm's (2006) findings yield in 1.5 days per decade overall, and 2.4 and 2.3 days per decade for the Estonian stations, matching GDD5 trends we found for Järvselja over almost the same period. More recent satellite retrieved data (Pulliainen *et al.* 2017) report a shift in the onset of spring recovery of 2.3 days per decade.

Strong fluctuations in the vegetation period length were especially visible in GDD10 in the beginning of 1960's and during the 1990's. In general, GDD10 had higher year-to-year fluctuation than GDD5. The change in the growing season is clearly seen (Fig. 2b) and the shift of the earlier start in the spring is stronger than the delay in the autumn (Fig. 2a). The change in the thermal growing season length we calculated for Järvselja is similar to the most of the Estonian weather service's stations but shows consistently about 5-7 days longer growing season estimates (Fig. S3 in Supplementary Information). Especially during the period from 1968 to 1975, the estimated growing seasons lengths were above the Estonian average. During the period from 1980 to 2002, the data were often at the upper end of the estimated growing seasons lengths, while during the most recent decades from 2003 to 2020 the data matched well with the Estonian average (Fig. S4 in Supplementary Information). The change in the growing season length has been slowing down towards the more recent years (Fig. 2b), and the active growing season length was again reduced to about 140 days during the years 2015 to 2020. The GDD5 length stabilized in this same time period to about 200 days.

The change in the growing season was also testable by the counts of extreme cold and warm days. Extreme cold days dropped from about 7.5 days in 1955 to just 2.6 days in 2020. In the autumn, cold extremes were lacking during the last 20 years, but also during the spring, colder periods and extreme cold days have gone scarce. The opposite trend is visible for extreme warm days (Fig. 1, Fig. 4, and Fig. 5) that increased from about 5 days in 1955 to 13 days in 2020. In 2018, a year with a strong heatwave (Krasnova *et al.* 2022) led to a record reading of more than 40 days with a daily maximum temperature above 25°C (Fig 4.). These findings are confirmed by Mann-Kendall trend tests, and for extreme cold days a decreasing trend of one day per decade ($p < 0.05$) and an increasing trend for extreme warm days of 0.75 days per decade ($p < 0.05$) were obtained.

The modelled changes in the growing season lengths at different meteorological stations distributed over Estonia (Fig. S3) show that the stations Tallinn, Ristna and Tiirikoja had stronger changes in the growing season length (> 2.5 days per decade) than the other stations. The significance analysis (Fig. S5) revealed that those estimated with a high statistical significance for a slope in the growing season change were Tallinn and Ristna, followed by Tiirikoja with medium statistical significance. Finally, Tartu, Pärnu, Viljandi and Järvselja had the lowest significance but were still meaningful predictors in explaining the response variable.

Discussion and conclusions

Based on our study, the length of the thermal growing season increased in the same scale as the general trend in the region. The rate of change is similar to the trends estimated at the Estonian meteorological stations with the exception of Tallinn and Ristna, both located

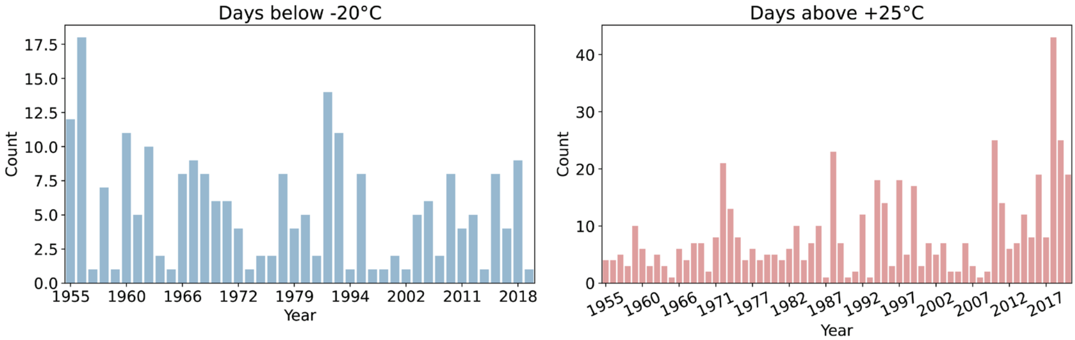

Fig. 4. The change in the number of extreme cold (below –20°C) and extreme warm (over 25°C) days per year over the 65-year period in Järvselja. Mann-Kendall test showed decreasing trend of extreme cold days and increasing trend of extreme warm days (h_0 and $p < 0.05$).

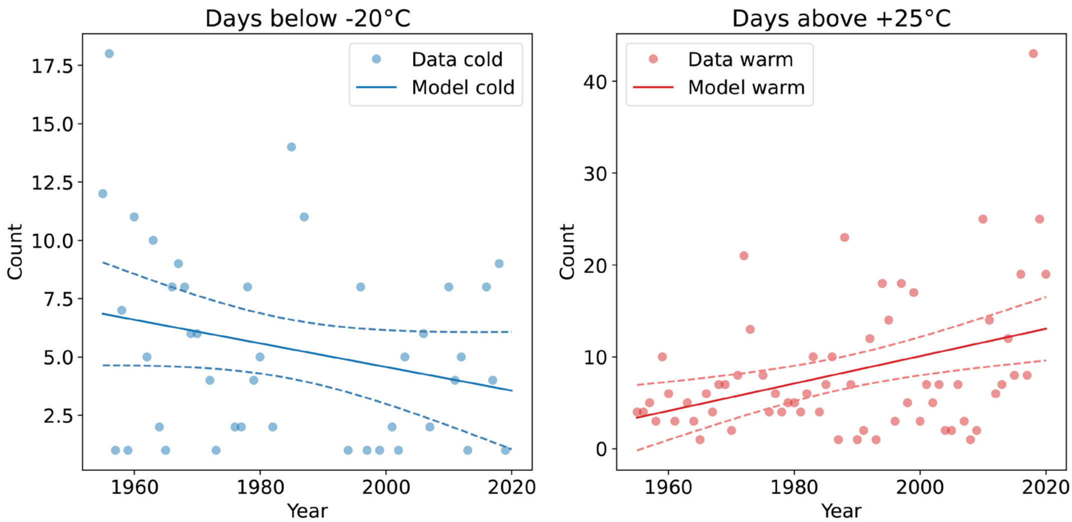

Fig. 5. Trends in the change of extreme cold or warm days in Järvselja. The number of extreme cold days has been dropped from about 7.2 to 2.6 days and the warm extremes rose from 3.4 to 13 days.

near to the sea. Being located in a forest area, the thermal growing season length is one of the longest compared with Estonian weather service station's data. Only the station in Ristna has a longer growing season in the last 25 years. Interestingly, the data from Järvselja match the average of the Estonian weather service stations well from 1955 until 1968. Then, it is well above the average until 1976 and then remains in episodes above the Estonian average until 2002. From that time on, the growing season length in Järvselja matches again the Estonian average (See Figs. S3-S5 in Supplementary Information). There might be several reasons for these differences, one being that the forest site in Järvselja is not an ideal place for weather measurements as prescribed by the WMO guidelines. Given the finding of Haesen *et al.* (2021), we could expect temperatures measured in or nearby a forest canopy to be lower during summer and higher during winter compared with open environment measurements. The process of evapotranspiration is cooling in summer months and the effect of shelter during winter is buffering the temperatures to some extent. From our data we can see that they match periodically very well to the Estonian average. Therefore, the site argument cannot be the only reason.

We noted that the measurement protocol was changed over time, and this could be another reason that might explain the difference between Järvselja and the Estonian average, because the data may be influenced by the sample procedure. We simulated all the three sample methods on the recent SMEAR Estonia data for which we have the highest data recording frequency (for details see supplemental material). This simulation experiment revealed that we do not get any bias by applying different sample methods. The protocol, mimicking the Six's thermometer, produced a wider ranged standard deviation but no shift in the mean. Overall, the weakest correlation coefficient between the measurement protocols was 0.94, which rules out the sampling protocol as a reason for the difference in the growing season length in Järvselja as compared with the Estonian average out. Additionally, there is strong support that the changes in the measurement protocols do not account for the differences between our data and the Estonian weather service's data. The years 1955 to 1968 show a match, and over time until 2001, they match only episodically. During these periods, no change in the measurement protocol occurred in Järvselja and therefore we can rule out the sample method as a reason for the difference between Järvselja and the Estonian weather service stations. We may conclude that because of the sufficient significance in the linear model, the growing season estimate based on the Järvselja 65-year dataset is a valid estimator.

An interesting finding is the stagnation or slight reduction in the growing season length during the last 10 to 12 years (Fig. 2). Especially GDD5, which remains at around 200 days, while the spring onset is getting again later and in the same years as the autumn end of the growing season gets later. At the same time, the number of extreme warm days is increasing and the number of cold days is decreasing (Figs. 4 and 5), and climate warming advances. According to Ruosteenoja *et al.* (2020), the modelled average length of the thermal summer will increase by nearly 30 days during the period 2040–2069 relative to 1971–2000, and the thermal winter will shorten by 30–60 days. We may speculate that the thermal growing season length reached nearly its maximum given the latitude and thereof the limitation of local radiation energy due to the short daytime during winter months for warming. Further increases in the global temperature may be a cause to lengthen the growing season further. Ruosteenoja *et al.* (2020) mention that the forest growth will not benefit from a longer growing season because of the lack of light during winter months.

In general, our findings are in line with Jaagus (2006) and Jaagus *et al.* (2017), proposing that the strongest warming period in Estonia occurred during the second half of the 20th century. The changes have occurred in both GDD5 and GDD10 lengths, caused by the earlier beginning of spring and the delayed start of the autumn and winter. Similar trends were found for other Baltic countries (Latvia, Lithuania) and European countries Europe (Linderholm 2006, Ruosteenoja *et al.* 2011) (cf. Table S1 in Supplementary Information).

The consequences of the changes in the vegetation period on forest ecosystems are not yet fully understood (Nemani *et al.* 2003, Angert *et al.* 2005, Canadell *et al.* 2007). While the earlier onset of the vegetation period may give advantage to a higher carbon uptake, e.g., Pulliainen *et al.* (2017) reported an increase of 3.7% per decade in GPP sums over the first half of the year from measurements and even higher rates (6.8% per decade) for modelled cumulative springtime GPP in Eurasian Forest ecosystems. Canadell *et al.* (2007) reported on the factors that increase and decrease carbon sequestration, and even though they reported a 6% increase in NPP over two decades attributed to the increasing vegetation period length, they also mentioned the bail out of this effect by increased in soil respiration due to the longer frost-free period. Angert *et al.* (2005) reported, in an analysis covering the Northern Hemisphere, that the increased uptake of carbon during early spring was cancelled out by a decreased uptake during summer, which was probably due to hotter and drier summers in mid and high latitudes. Such an effect was shown in earlier studies (Ciais *et al.* 2005), coinciding with our measurements (Krasnova *et al.* 2022) at the SMEAR station and over southern Estonia that heatwaves cause strong decreases in GPP, resulting up to 30% drop over Europe. The increasing number of extreme hot days (Figs. 4 and 5) confirm that these processes will also change the carbon sequestration patterns in the hemi-boreal forest ecosystem (Holmberg *et al.* 2019, Ruosteenoja *et al.* 2020).

In conclusion, we could confirm our hypotheses, that the modelled slope of change in Järvselja is similar to the Estonian weather service's reported regional changes during the thermal growing season. Our result further match to the reported decadal changes in the literature. From the simulated sampling method, we found a wider range in standard deviation for the daily data but no bias in the daily mean.

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