LENGTHENING OF THE THERMAL GROWING SEASON DUE CLIMATE CHANGE IN ESTONIA

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In higher latitudes, including Estonia, climate change is expexted to extend the thermal growing season and the physiologically effective part of it. Thermal growing season is the time of year when the mean daily temperature exceeds +5 ºC, while the effective temperature sum includes the part above five degrees of mean daily temperature. In Estonia the length of growing season is 180-195 days, during the 50-year period (1965-2014) it has prolonged by about 2 weeks by trend, mostly due to the earlier spring. On average the vegetation starts 17 days earlier in south and 10 days earlier in north.

The results of two emission scenarios, B1 and A2, were applied for two regions. All projections indicate temperature increase, higher warming is supposed to take part during the cold part of the year, lower during the growing season. By 2050, growing season is projected to lengthen on average by 16-24 days in northern and 18-28 days in the southern parts of Estonia. The effective temperature sum of the growing season is also projected to increase considerably. If greenhouse gas emissions continue rising (scenario A2), the effective temperature sum in Estonia would allow maturation of grain maize by 2100.

Keywords: climate change, growing season, Estonia

INTRODUCTION

Climate has always been changing and this will certainly continue in the future (IPCC, 2007a), while in high latitudes, including Estonia, temperature rise is expected to be even stronger than elsewhere (IPCC, 2007b). One significant impact of climate change is its effect on agriculture. Schimel (2006) has written that, at least is some regions, agriculture may be one of the bright spots, „the silver lining in the climate change cloud“. Nordic countries may indeed be one of such regions. According to the review presented by the BACC II Author team (2015), several studies report a shortening of the thermal winter and prolongation of the thermal growing season in Northern Europe within the history of meteorological observations. Similarly, in Estonia there has been general tendency towards an earlier onset of the climatic seasons in the vernal half of the year and a later start in the autumnal half, although not always statistically significant (Tarand et al., 2013). Increases in the length and warmth of the growing season may improve the agriculture potential in high latitudes (Peltonen-Sainio et al., 2009).

In this paper, we estimate how the length (and timing) of the growing season is projected to change in Estonia during the ongoing century. Additionally, changes in accumulated effective temperatures are analysed, which gives measure for the integrated warmth of the growing season. The estimates are based on temperatuure projetions simulated by 4 GCMs. Two greenhouse gas scenarios, B1 and A2, are considered.

MATERIALS AND METHODS

To obtain temperature data for the middle and end of the current century (hereafter marked as projections for the target years 2050 and 2100), climate change scenarios were generated using a simple coupled gas-cycle/aerosol/climate model MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) that drives a spatial climate-change SCENario GENerator (SCENGEN) (http://www.cgd.ucar.edu/cas/wigley/magicc/). This is a software that enables to investigate future climate change based on emissioon scenarios for greenhouse gases, reactive gases, and sulphur dioxide. MAGICC consists of the software that estimates the global annual mean surface temperature and sea level rise for particular emission scenarios. Thus, it is a tool for comparing the global implications of scenarios. SCENGEN is a regionilisation algorithm using a scaling method developed by Santer et al. (1990), which constructs a range of spatially detailed climate change scenarios. The algorithm exploits three sources of data – the output from MAGICC, results from the CMIP3/AR4 archive of GCM experiments, and a dataset of observed globaal and regionaal climate trends from 1980-1999 at 2.5° x 2.5° resolution – to produce spatially detailed information on future changes in the temperature, precipitation and mean sea-level pressure. MAGICC/SCENGEn has been one of the pimary models used by the IPCC since 1990 to produce projections of the future global mean temperature and sea level rise. We used ver. 5.3.v2 of the software. Information on the Basic properties of MAGICC has been published by Wigley and Raper (1992) and Hulme et al. (2000).

Because projections of climate change depend heavily on human activity, climate models are run against scenarios. There are over 40 different emission scenarios in the Special Report on Emission Scenarios (SRES) prepared by IPCC (2001). Two alternative illustrative scenarios were used in our study to generate climate change scenarios for Estonia: milder B1 and stronger A2. For both scenarios, we exploited predicted changes in mean monthly temperatures from four IPCC AR4 GCM experiments (IPCC 2007a) (Table 1). The choice of models was based on a recent research by Jaagus and Mändla (2014), who explored control experiments for the estimation of different GCMs to describe climatic conditions in Estonia.

In this study, the target years 2050 and 2100 (i.e. the central years for a climate averaging interval of 30 years) were chosen as outcome years and the year 1990 was used as the reference year, and all the climatic changes are calculated with respect to this year.

Table 1. GCMs used in the study

Model	Institution
NCAR_ CCSM-3	*National Center for Atmospheric Research*
NIES_M IROC3	*CCSR/NIES/FRCGC*
MPIM_ ECHAM5	*Max Planck Institute for Meteorology*
UKMO_ HadGEM	*Hadley Centre for Climate Prediction and Research*

MAGICC/SCENGEN simulates monthly climate anomalies (mean future climate minus mean present climate). In our case, those are absolute temperature anomalies (in °C), determined by four GCMs for both scenarios and two grid boxes. To obtain future daily weather data, daily data of 50 years (1965-2015) were used as basic series. Further on, we use the term "reference period" to indicate that time period. Adding corresponding monthly changes predicted by MAGICC/SCENGEN to each day's values, four series of 50-years long datasets of air temperature were obtained for each scenario and target year. This way, not just only one average future set of predicted temperature, but the possible temperature distributions (2 scenarios X 4GCM X 50 years = 400 alternatives) are suggested for both target years and stations. Additionally, the sets of data obtained by using average climate anomalies over different GCMs were applied in comparative calculations.

The same set of the weather data (observed and computed) was employed to derive the information about the changes in vegetation period. In the current paper, we define thermal growing season as the time of year when the mean daily temperature exceeds +5 ºC, thus the length of the vegetation period was calculated by the dates of the permanent increase of daily mean temperature above 5 °C in spring and drop below 5 °C in autumn. The effective temperature includes the part above +5 °C of mean daily temperature. The sum of effective temperatures over the growing season measures the accumulated warmth throughout the season and is expressed in degree-days (°Cd). Due to different climatic conditions, definitions of thermal seasons may vary in different countries. Likewise, a reasonable base temperature for thermal growing season depends on the crop under consideration. For instnce, we apply a 10 °C threshold temperature for an example with maize, as suggested by, e.g. Fronzek and Carter (2007).

RESULTS

Climate change projections

All climate change projections indicate temperature increase in Estonia. Higher warming is supposed to take part during the cold part of the year, lower during the growing season (Fig. 1). The warming is quite similar for two different regions of Estonia, therefore the current temperature differences between regions are not expected to change much. The projections however split quite noticeably between emission scenarios, especially for the further target period. Mean monthly temperatures by mid-century, projected under stronger A2 scenario, are nearly identical to those under milder B1 scenario by 2100.

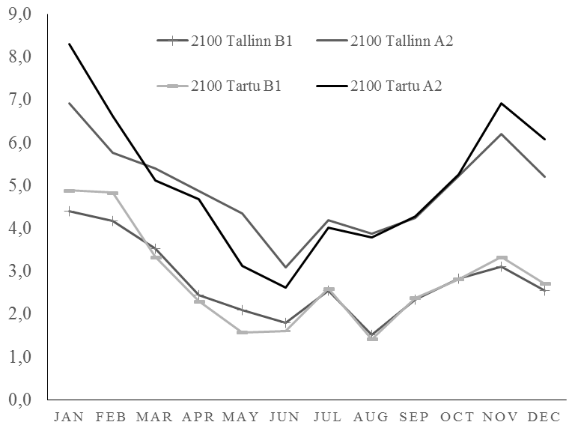

Figure 1. Changes in the monthly mean temperature (°C), as an average over 4 selected global climate models for the severe A2 and modest B1 emission scenarios for year 2100 compared to the baseline period (1961-1990) at two Estonia sites.

Table 2. Mean monthly values of air temperature (°C) at the two observed stations of the plant-growth period in the period 1965-2014, and by two emissioon scenarios by 2050 and 2100.

STATION	MONTH	Mean temperature, °C				
		1965-2014	2050		2100	
			B1	A2	B1	A2
TARTU	APR	5.0	6.4	7.2	7.3	9.6
	MAY	11.2	12.1	12.7	12.8	14.3
	JUN	15.2	15.9	16.4	16.8	17.8
	JUL	17.4	18.5	19.1	20.0	21.4
	AUG	16.0	17.1	17.8	17.4	19.7
	SEP	11.0	12.3	12.8	13.4	15.3
	OCT	5.8	7.3	7.9	8.6	11.0
TALLINN	APR	3.9	5.4	6.2	7.0	9.3
	MAY	9.8	11.1	11.9	11.9	14.1
	JUN	14.3	15.2	15.8	16.1	17.4
	JUL	17.0	18.2	18.9	19.6	21.2
	AUG	15.8	17.0	17.7	17.4	19.7
	SEP	11.2	12.5	13.0	13.6	15.5
	OCT	6.2	7.8	8.4	9.0	11.4

Vegetation period

In Estonia the current length of growing season is 145-216 days in selected regions (Table 3). Vegetation generally starts earliest in southwestern part of the country (including Tartu) and latest in western and northern coast (including Tallinn), where influence of the Baltic Sea tends to delay the arrival of spring. On the contrary, the end of vegetation period occurs earlier on the mainland and later on islands and coastal area. During the 50-year period vegetation period has prolonged by about 2 weeks by trend, mostly due to the earlier spring. On average the vegetation now starts 17 days earlier in south and 10 days earlier in north (Table 3).

Table 3. Beginning, end and length of the thermal vegetation period in two different parts of Estonia and their change by trend over 1965-2014.

	Tallinn			Tartu		
	Start	End	Length, days	Start	End	Length, days
Mean	24.04	24.10	184	17.04	21.10	187
Min	05.04	28.09	160	21.03	25.09	145
Max	14.05	17.11	216	5.05	14.11	215
Change by trend, days	-10	+4	+14	-17	+2	+19
P	0.008	0.472	0.070	0.001	0.751	0.019

The projected increase in temperature suggest that growing season will lengthen further, on average by 15-25 days by 2050 and 33-73 days by 2100, depending on emission scenario (Table 4). All selected models predict lengthening of the vegetation period, and the projected change is statistically significant compared to reference periood (1965-2014) ($p<0.05$) by most models. Only CCSM-30 projects milder change, which is only significant if longer period and wilder scenario is considered. Differences between emission scenarios became quite substantial for longer target period, indicating large incertainity of the predictions. Average differences between regions are not very marked, while for individual years those differencies can still remain large.

Table 4. Projected average changes (in days) in the start, end and length of vegetation period by target years 2050 and 2100 and two emission scenarios in two Estonian location averaged over 4 GCMs.

Target year	Scenario	Tallinn			Tartu		
		Start	End	Length	Start	End	Length
2050	B1	-7	+11	+17	-6	+10	+15
	A2	-13	+14	+25	-10	+14	+25
2100	B1	-21	+17	+36	-14	+20	+33
	A2	-41	+33	+73	-36	+36	+73

Vegetation period, which currently starts in the end of April on average, is predicted to start in the beginning of April by 2050 and even in the middle-March by the strongest scenario by 2100 (Table 4, Figure 2). While until now, the lengthening of the vegetation period has mostly occurred in the spring, for the future, the end of thermal vegetation period is also moving significantly, from middle-October to early or even late November. However, the lengthening of the growing season in the autumn is not likely to support growth as effectively as lengthening in the spring, because of the light intensity and short days.

Accumulated effective temperatures

The predicted increase in effective temperature sum during the growing season is considerable (Table 5). This number characterizes the physiologically effective part of the growing season, which supports crop growth and development. Currently (1965-2014) the average length of the growing season is around 1500 °Cd in Tartu and 1400 °Cd in Tallinn. Generally, the effective temperature sum is predicted to rise by 150-250 °Cd and by 450-1000 °Cd by 2050 and 2100, respectively. Again, great differences between emissioon scenarios turn those predictions indefinite. While for the first projection period, the two contrasting scenarios do not diverge too much, later the high-emission A2 scenario projects considerably stronger increases.

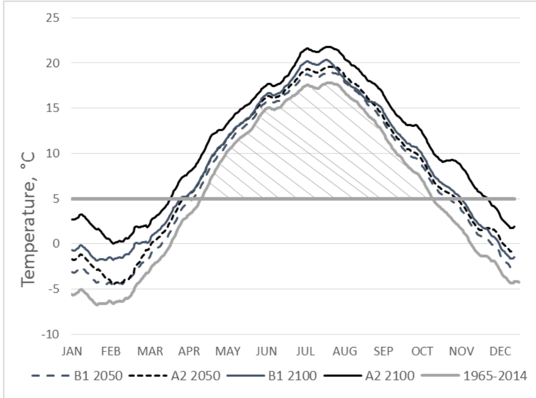

Figure 2. Evaluation of the growing season and effective temperature sum for present climate (1965-2014) and as projected under B1 and A2 emission scenarios by 2050 and 2100 for Tartu. Vegetation period starts when the temperature curve with a positive slope intersects the 5 °C level, indicated by a horizontal line on the figure. Correspondingly, that threshold defines the end of growing seaon, when the slope of the curve is negative. The streaked section between the 1965-2014 curve and the 5 °C threshold line displays the present-day effective temperature sum of the growing season, while area between observed and projected curves indicates possible increase in the accumulated heat in the future.

In relative terms, the effective temperature sum increases more rapidly than the length of the growing season. This can be easily understood by examining Figure 2. As also stated by Ruosteenoja et al. (2011), the response of the temperature sum is roughly proportional to the square of the temperature increase, being influenced both by the length and the mean temperature of the growing season.

Table 5. Average effective temperature sums (°Cd) for reference period and as projected by two emission scenarios by 2050 and 2100 for two Estonian locations.

Period	Scenario	Tallinn	Tartu
1965-2014		1400	1500
2050	B1	1650	1750
	A2	1750	1850
2100	B1	1900	1950
	A2	2450	2500

As an example of the implications of the longer/warmer growing season, we look at the thermal suitability for maize. Maize is a crop favouring high temperatures, therefore higher base temperature is used for calculating effective temperature requirements fo grain maize, as suggested by, e.g. Fronzek and Carter (2007), Yi *et al.* (2010), Hou et al. (2014). The minimum effective temperature sum over a base temperature 10 °C for grain maize maturation is around 700-850 °Cd (Carter et al. 1991, Martin et al. 2006, Fronzek and Carter 2007). Under the present conditions, the 850 °Cd (> 10 °C) threshold condition is only met in 6 % and 18 % of the years in Tallinn and Tartu, respectively (Figure 3 for Tartu). Therefore, as can be expected, maize is presently only grown in Estonia as a marginal forage crop. If climate warming proceeds by A2 scenario, temperature sums will definitely be suitable for grain maize maturation in Estonia by 2100 in both observed stations, while by 2050 64 % and 75 % of the years may reach the threshold in Tallinn and Tartu, respectively. Milder scenario is not so gracious, however even under B1 conditions, the 75 % probability of maize maturing is assumed to be met by the end of the century.

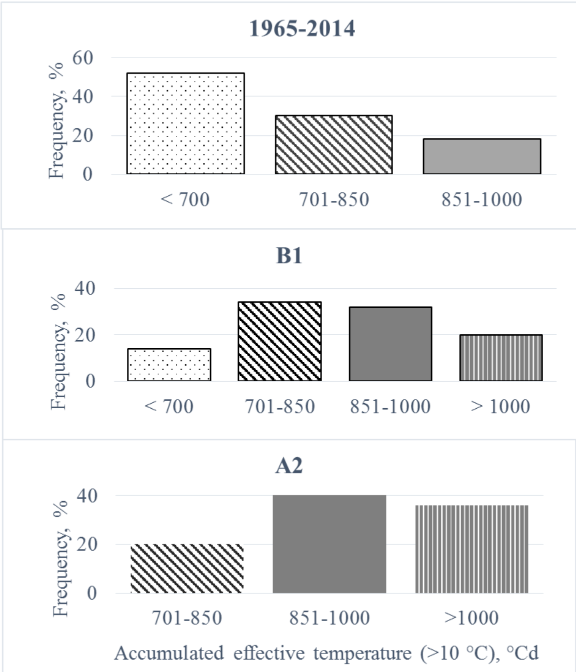

Figure 3. Frequency of years, when effective temperatures accumulated over the whole growing season (>10 °C) falls into different thermalclasses, for reference climate and under two climate change scenarios by 2050 at Tartu. Temperature sums under 700 °Cd are not sufficient for grain maize, temperature sums 700-850 °Cd is questionable and with thermal accumulation over 850 °Cd maize is able to maturate.

CONCLUSIONS AND DISCUSSION

The research suggests that climate change offers some new opportunities for agriculture in Estonia (and similar regions). General warming will lead to quite remarkable extension of our presently too short growing season. In addition to the season lengthening, more warmth will accumulate and be available for plant growth. If the climate will warm according to model projections, Estonian thermal conditions will be similar to present-day central Europe by the end of the century. This means that cultivation of new species/varieties becomes possible and probable.

However, merely focussing on longer growing season and higher accumulated temperatures may draw false, too optimistic image of the future. Thermal conditions similar to central Europe do not mean that conditions for plant/crop growth will be similar as well. Growing crops under intense spring/summer daylight combined with elevated temperatures from one side and scarsity of light towards autumn/winter despite of elevated temperatures poses quite few new challenges.

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