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Synopsis

Thermal Growing Season Characteristics over Central and Southeast Europe in the Changing Climate 1950-2019

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Abstract. The ongoing climate change is profoundly important for ecosystems, for all sectors of the international economy, and on the quality of life. Managed systems as agriculture and forestry are evidently most dependent on climate and the climate changes have a direct and indirect impact on biotic and abiotic disturbances with strong implications. Among others, temperature is one of the major environmental factors affecting the growth, development, and yields of crops. The timing of the onset and termination of the vegetation growing season plays a key role in terrestrial ecosystem carbon and nutrient cycles. Based on the availability of reliable and up-to-date sources of information, which represent the temperature distribution in a pan-European context, the study exploits a set of 4 indicators with a special focus on the onset, termination, and length of the thermal growing season. It is defined by a single-value threshold of the daily mean air temperature. Two thresholds are applied: 5°C and 10°C. Among other conclusions, the study provides strong evidences for the prolongation of the thermal growing season. This lengthening is a direct consequence of the ongoing warming and is consistent with most new studies. Another key message, which confirms our recent findings is the revealed asymmetry of this prolongation: the total lengthening of the thermal growing season is caused in greater extent to the shifting to an earlier date of the onset, rather than to its later termination.

Key words: thermal growing season, climate change, seasonal shift, trend analysis.

Introduction

The ongoing climate change is the defining challenge of our time which exerts influence on the ecosystems, on all sectors of the international economy, and the quality of life. Climate change evokes an increasing frequency of climate extremes and the subsequent adverse effects are manifold (Alexander et al., 2006; Lavaysse et al., 2017).

The global warming effects and the associated regional climatic changes over Central and Southeast (CSE) Europe have been profoundly studied in the last decades using data from various sources (Bartholy & Pongracz, 2006; Birsan et al., 2014; Chervenkov & Slavov, 2020; Cheval et al., 2014; Lakatos et al., 2013, 2016). Most of these studies are focused on the second half of the 20th and the first decade of the 21st century, clearly evidencing that, similarly to the global and continental trends, the regional temperature got higher during the period.

Food security is a fundamental precondition for human well-being, and the

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agricultural and food sector is of major economic importance. Agriculture is arguably the sector most dependent on climate. Crops and livestock are directly impacted by adverse local weather and climate (Hatfield & Prueger, 2011; 2015; Seemann et al., 1979). Associated with climate change several factors are affecting agricultural ecosystems, which can act independently or in combination (Harkness et al., 2020). As evidenced in many recent publications, the climate changes have a direct and indirect impacts on biotic and abiotic disturbances with strong implications.

Temperature is one of the major environmental factors affecting the growth, development, and yields of crops. On one hand, crops have a basic requirement for the temperature to complete a specific phenophase or the whole life cycle. On the other hand, extremely high and low temperatures can have detrimental effects on crop growth, development, and yield, particularly at critical phenophases (Luo, 2011). Changes in thermal conditions may also have adverse effects such as the development of thermophilic weeds, pests, or the emergence of new plant diseases (Szyga-Pluta & Tomczyk, 2019). The thermal impact could be quantified by various agrometeorological (AM) indicators (Harding et al., 2015) and among the most widely used is the thermal growing season (TGS). The timing of the onset and termination of the vegetation growing season plays a key role in terrestrial ecosystem carbon and nutrient cycles (Liu et al., 2016). The precise knowledge of these dates is necessary also for the calculation of climatic indicators with evident effect on the production of many cultivars (Mesterhazy et al., 2018). During the last decades, an increasing number of studies have revealed a lengthening of the growing season across the Northern Hemisphere that is related to air temperature increases, and thus this is an important indicator of climate change (see Menzel et al, 2003 and references therein). Changes in the start and end dates as well as the length of the growing season, in addition to the consequences for ecosystems, may lead to long-term changes in the carbon dioxide cycle, and changes in vegetation will affect the climate system (Linderholm, 2006).

The purpose of the present paper is to assess the multiyear spatial patterns and as well as to estimate the trend of the temporal evolution of the onset (i.e. start day), termination (end day), and length of the TGS over CSE Europe for the 70-years long period 1950–2019. Following the traditional approach, these indicators are defined by single-value thresholds of daily mean air temperature, noted for sake of brevity tg henceforth, using the high-quality and high-resolution (0.1°×0.1°) multivariate daily gridded dataset E-OBSv21.0e (Cornes et al., 2018). Our group has previous experience of regional climatological studies with a focus on the growing season length (GSL) of the past and recent (Chervenkov & Slavov, 2019; 2020; 2021a; b) as well as projected future climate (Ivanov et al., 2020; Chervenkov & Slavov, 2022) and the presented study could be regarded in the general context of the continuation of our recent efforts.

Material and Methods

The well-known in the climatological community gridded daily dataset E-OBS was developed primarily for regional climate model evaluation, but it is also being used subsequently for various applications, including monitoring of extremes. Besides the improved quantification of the uncertainty, the ensemble version of the E-OBS (Cornes et al., 2018), represents generally better than predecessors the temperature extremes. As demonstrated in (Chervenkov & Slavov, 2019) E-OBS is a suitable product for the computation of climate indices which motivates our choice of it for a source of input data.

Unlike some other AM indices which computation could be performed in different ways, the GSL definition is agreed in frames of collaborative initiatives like the European Climate Assessment & Dataset (ECA&D) project and Expert Team on Climate Change Detection and Indices (ETCCDI) (Zhang et al., 2011). For many applications, such as the description of forest and agricultural regions or the integration of the length of the growing season in models, a plant-independent and more general definition is of interest (Menzel et al., 2003). According to the unified definition of ECA&D and ETCCDI, the GSL is the annual count between the first span of at least 6 days with tg>tb and the first span after July 1 (in Northern Hemisphere) of at least 6 days with tg<tb (Zhang et al., 2011; Birsan et al., 2014). The GSL is computed on annual basis and the units of measurement are days. Although some alternative definitions, respectively calculation methods, exists (Linderholm, 2006), we will follow strictly the ECA&D and ETCCDI one.

The threshold temperature tb is in the definition above equal to 5°C which is suitable for the cold-tolerant cultivars. This threshold is probably most frequently used in the computation of the climatological TGS (Szyga-Pluta & Tomczyk, 2019). In the present study, in particular, due to the geographical location of the region, we will estimate the GSL also for tb=10°C which is a threshold for the thermophile species (Ivanov et al., 2020; Lakatos et al., 2013).

Due to its importance, the GSL is the subject of many studies, considering the global and regional climate (see, for example, Menzel et al., 2003; Mesterhazy et al., 2018 and detailed list in Linderholm, 2006), whereas relatively smaller attention is paid on its onset day of the year (DOY) and termination DOY, noted further as in (Chervenkov & Slavov, 2021b) DOYB and DOYC respectively. Changes in the timing or the seasonality and not only in the length of the growing season, however, may have essential relevance for plant ecosystems. The essential importance of DOYB and DOYC is the main motivator to consider them in the present study.

The definition of the GSL gives the possibility for straightforward computation of the DOYB and DOYC. The time series of the tg of the first/second half of the year is inspected for the first occurrence of a continuous period of six days where the tg is above/bellow tb. The computations are performed with purpose-built software and for each gridcell of the domain individually. According to the original proposal in (Chervenkov & Slavov, 2021b, 2022), the middle day of the growing season (DOYM), where DOYM=(DOYB+DOYC)/2, is an indicator of the seasonal shift which is independent of the GSL. It is also considered in our study as will be demonstrated in the next section.

Results and Discussion

First, to assess the long-term inter-annual changes, the multiyear means (MM) of the DOYB, DOYM, DOYC, and GSL for the first 30 years, i.e. 1950-1979 are superimposed to these for the last 30 years, i.e. 1990-2019. The absolute difference of the MM for the second period in respect to the first (i.e. (1990-2019)-(1950-1979)) is applied as a measure of the long-term change. The comparison is performed for both thresholds of 5°C and 10°C separately and the results are shown in Fig. 1 and 2 correspondingly. Intending to make the comparison of both figures easier, the same color legend is used.

Many conclusions could be outdrawn from both figures. The first and most noticeable is the clear spatial structure of all of the considered quantities. As noted in the study (Birsan et al., 2014), regarding some ETCCDI-indices, the vertical gradients are better expressed than the horizontal ones. As expected, the growing season onset is earlier and its termination is later in the regions with generally warmer climate – the southern coastal areas. The GSL is shortest over the NW part of the domain and especially over the mountains, most prominent over the main Carpathian ridge (MCR).

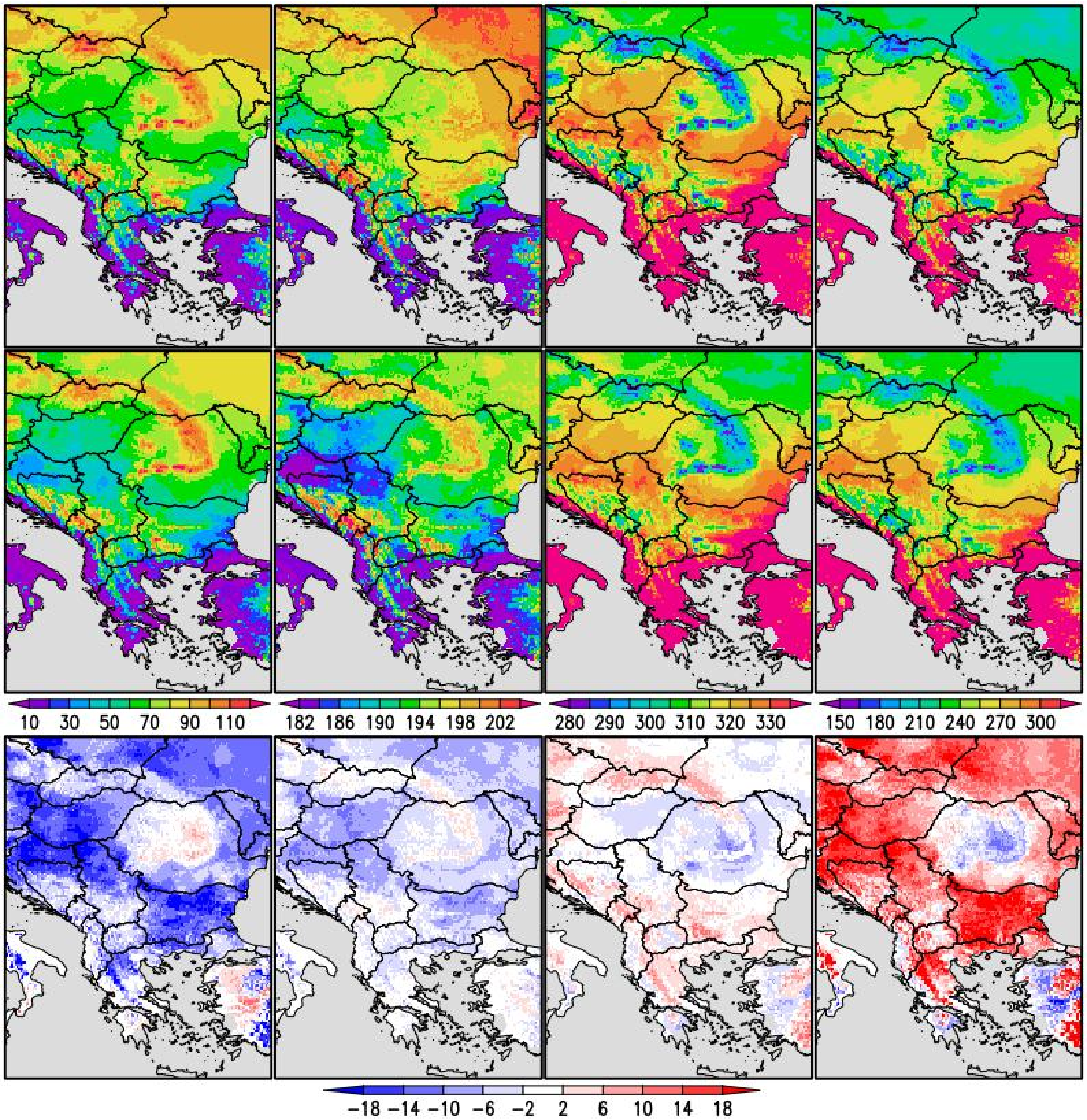

Fig. 1. From left to right: MM of the DOYB, DOYM, DOYC and GSL for the threshold of 5°C for the period 1950-1979 in the first and for 1990-2019 in the second row. The differences (1990-2019)-(1950-1979) are shown on the third row. The units are DOYs for DOYB, DOYM, DOYC and days for GSL and for the differences.

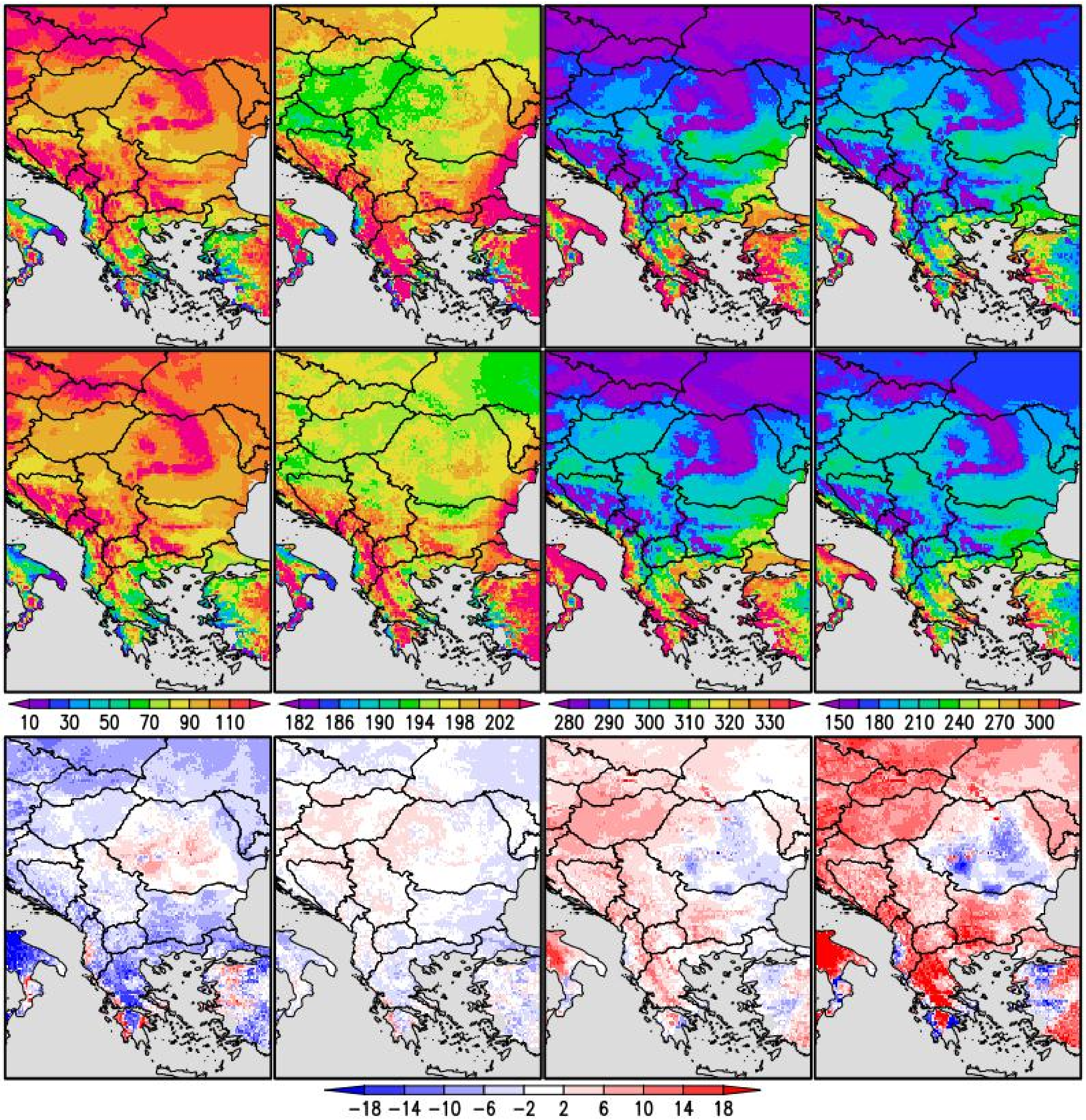

Fig. 2. Same as Fig. 1 but for the threshold of 10°C.

As a whole, the GSL varies significantly: roughly from 180 to more than 300 days for the threshold of 5°C and from 150 to 300 days for the threshold of 10°C. The differences between the MM of both periods are also remarkable: the generally warmer climate in the second period leads to spatially dominating earlier onset and later termination of the growing season. As result, the GSL is lengthened with more than two weeks over the bigger part of the considered domain. Generally, the tendencies are better expressed for the threshold of 5°C. The long-term changes are also bigger for the DOYB rather than these of DOYC. Evidently, the regional warming leads to asymmetric changes of the timing of the GSL. A direct consequence from this is that the DOYM is shifted to earlier dates, more noticeable for the threshold of 5°C.

The latter findings are in principle agreement with the results of similar studies and our recent outcomes. One of the key messages in (Menzel et al., 2003) is that the lengthening of the growing season over Germany, Switzerland, Austria, and Estonia can mostly be attributed to advances in spring phenology rather than the delay of autumn. One of the main conclusions of the study (Chervenkov & Slavov, 2021b) which considers CSE Europe and the period 1961–2018, is that the total lengthening of the GSL for the threshold of 5°C is caused in greater extent to the shifting to an earlier date of the onset, rather than to its later termination.

Hence the long-term inter-annual changes of the parameters of the TGS are in the focus of our study, their temporal evolution should be also considered. Fig. 3 shows the time series of the areal averaged (AA) over the whole domain of the DOYB, DOYM, DOYC, and GSL for both temperature thresholds.

The most important result of the analysis of Fig. 3 is the clear increasing course of the GSL for both temperature thresholds, especially noticeable after the eighties. The downward and upward tendency of the DOYB and DOYC correspondingly could be also detected, although they are not so apparent.

The importance of assessing the long-term trends is often emphasized (Alexander et al., 2006; Bartholy & Pongracz, 2006; Chervenkov & Slavov, 2019). The primary reason is to estimate the sustainability of the detected inter-annual changes. In the present study, the magnitude of the trend is estimated with the Theil-Sen Estimator (TSE) and its statistical significance is analyzed with the Mann-Kendall (MK) test. The TSE and the MK test are procedures, especially suitable for non-normally distributed data, data containing outliers and nonlinear trends. Consequently, they are widely used in many engineering and geophysical branches as hydrology. They are recommended from the World Meteorological Organisation [24] and are practically standard tools for statistical assessment of trend in the meteorology (Chervenkov & Slavov 2020; 2021a; b; Cheval et al., 2014; Lakatos et al., 2016).

The results from the trend analysis of the GSL-related measures are shown in Fig. 4. Traditionally, (Chervenkov & Slavov 2021a; b; Cheval et al., 2014; Lakatos et al., 2016) the results were evaluated at the significance levels of 5%.

According to the results of the analysis of Fig. 4, first and foremost is the prevailing positive tendency for DOYC and especially for the GSL; contrary, the overall trend for the DOYB and DOYM is negative. Generally, the trend appears statistically significant over a relatively big part of the domain for DOYB and GSL only. There is no principal disagreement of the revealed tendencies for the threshold of 5°C on the one hand and for the threshold of 10°C on the other. As a whole, the tendencies, however, are better expressed for the lower threshold.

In the present study Bulgaria is the focus of the author's interest. The estimated parameters of the trend of the AAs of the considered TGS-characteristics for the whole domain noted for sake of brevity CSE Eu, one the one hand are superimposed to their counterparts for Bulgaria ('Bg' - the area in the green box in Fig. 4) on the other hand. A measure magnitude of the trends is the slope of the regression line β_0 computed according to the TSE and of its significance - the p-value of the MK-test. The results are shown in Table 1.

The numbers in the first row of Table 1 are the values of the slope of the trend lines of the time series, shown in Fig. 3.

The results in Table 1 could be summarized in many directions. First and foremost is the positive and statistically significant trend of the most important indicator, the GSL. This is valid for both domains and for both thresholds. The trends of the DOYB and DOYM for the more recognizable threshold of 5°C of are, as expected, negative and statistically significant. Contrary, the changes of the DOYC, both positive, are not statistically significant at the chosen level.

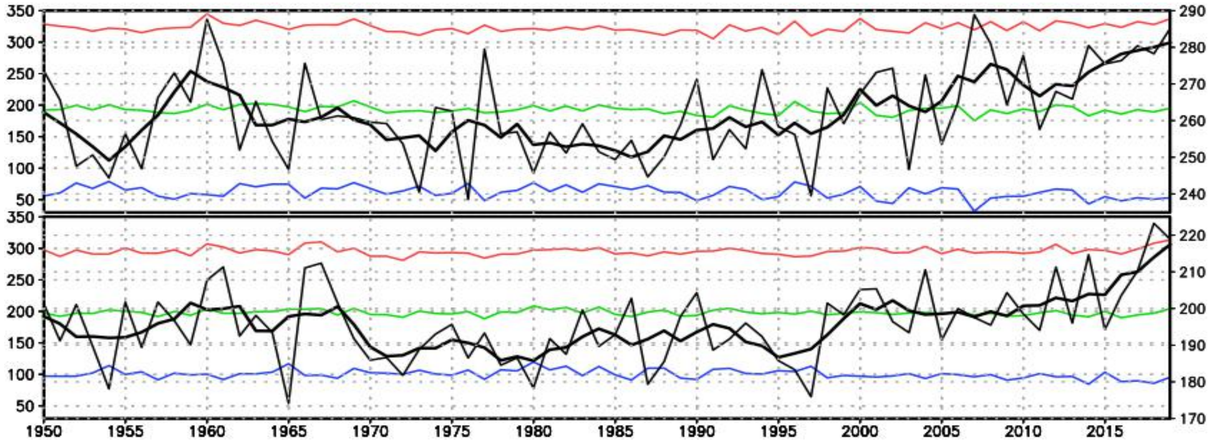

Fig. 3. Upper pane: temporal evolution of the DOYB (blue line, left ordinate), DOYC (red line, left ordinate), DOYM (green line, left ordinate) and GSL (black line, right ordinate, units: days) for the threshold of 5°C. The fat black line is the centered 5-year running mean of the GSL. Lower pane: Same as upper pane but for the threshold of 10°C.

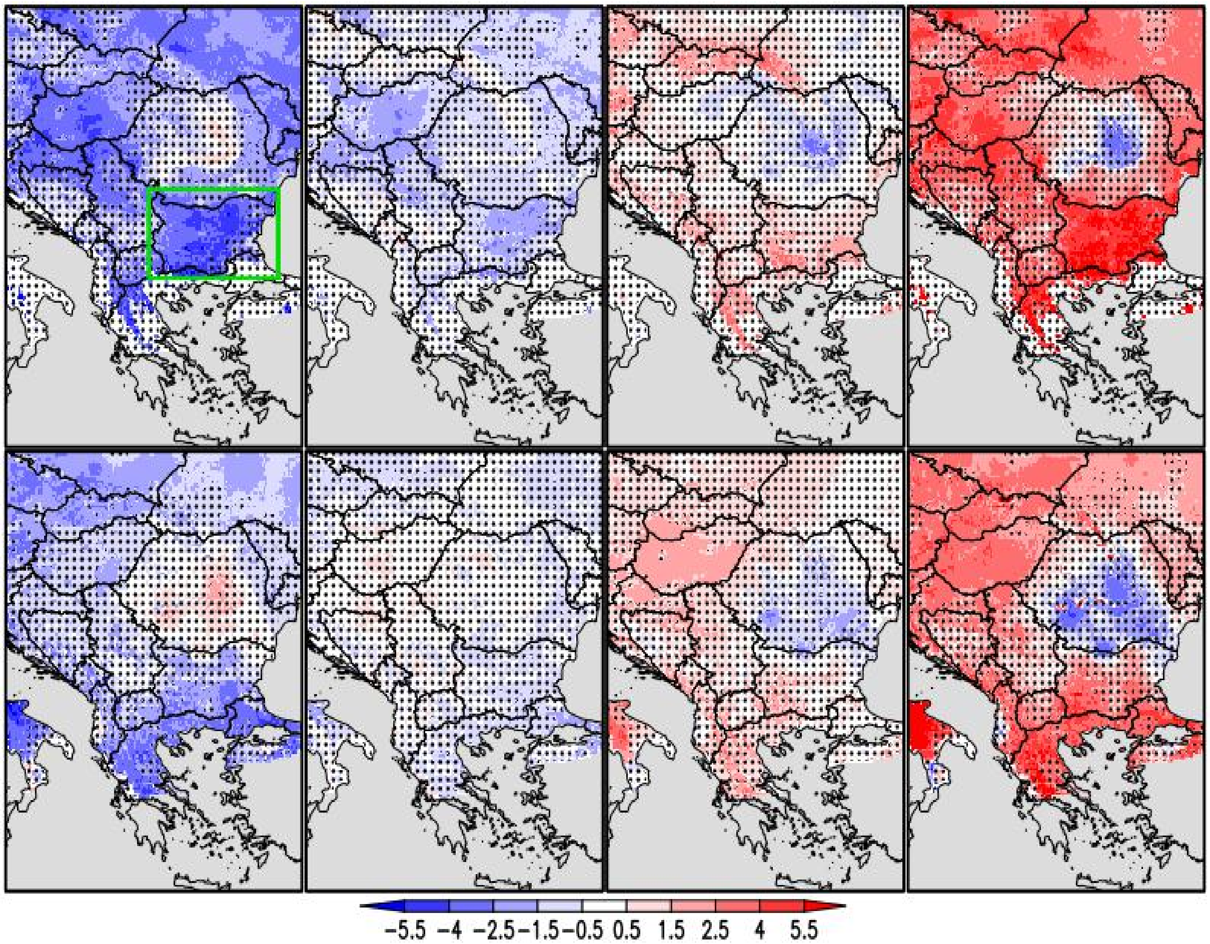

Fig. 4. Trend magnitude (unit: days per 10 years) of the DOYB, DOYM, DOYC and GSL (from left to right) for the threshold of 5°C (first row) and for the threshold of 10°C (second row). Stippling indicates grid points with changes that are **not** significant at the 5% significance level. The area in the green box in the first subplot is used in later analysis.

Table 1. Trend magnitude and significance of the AAs of the growing season indicators for the whole domain (CSE Eu) and for Bulgaria (Bg). The trends that are **not** significant at the 5% significance level are shown in bold.

Parameters/Threshold	Threshold of 5°C				Threshold of 10°C			
	DOYB	DOYM	DOYC	GSL	DOYB	DOYM	DOYC	GSL
β_0(d./10 yr), CSE Eu	-1.9	-0.7	0.17	2.3	-0.9	-0.4	0.4	1.4
p-value, CSE Eu	0.002	0.040	**0.715**	0.006	0.021	**0.205**	**0.222**	0.018
β_0(d./10 yr), Bg	-3.3	-1.2	1.06	4.4	-1.5	-0.6	0.3	1.6
p-value, Bg	0.001	0.021	**0.139**	0.002	0.027	**0.105**	**0.637**	**0.139**

The long-term tendencies of the considered indicators at the threshold of 10°C are more complex. Most generally, they are with the same sign as their counterparts for the lower threshold. According to their magnitude they are, as a whole again, weaker. The trends of DOYM and DOYC are statistically not significant for both domains; even the tendency of the GSL for Bulgaria is not significant.

The complexity of the revealed picture implies further investigation, in particular applying different methods for the determination of the TGS and other, independent basic datasets.

Conclusions

Based on the availability of up-to-date data, we present an analysis of the characteristics of the thermal (i.e. climatological) growing season over CSE Europe for the second half of the 20th and the first two decades of the 21st century. To determine the TGS, we used two single-value thresholds, based on td, namely 5°C and 10°C. Although not exhaustive, the study gives clear evidence of its lengthening which is in the principle agreement with many studies for the mid and higher latitudes of the Northern Hemisphere revealed from different data sets, such as station network measurements, satellite images, CO_2 records, and phenological 'ground truth' (Menzel et al., 2003; Szyga-Pluta & Tomczyk, 2019). This outcome confirms also our recent findings (Chervenkov & Slavov, 2021b). The increasing length of the growing season appears in a form of an earlier onset and a later termination. Alongside the other results the most important key messages could be summarized as follows:

The total lengthening of the TGS is more linked to its earlier onset rather than the later termination.

Direct consequence of the above result is the steady seasonal shift of the TGS towards the earlier dates. The conclusion is confirmed also with the revealed negative trend of the middle day of the TGS (DOYM). This trend is also statistically significant at the 5% level for the AAs values of the DOYM.

The revealed long-term tendencies are generally similar for both thresholds. The tendencies for the upper threshold, 10°C are, as a whole, weaker.

The revealed tendencies for the more recognizable threshold of 5°C are, both in magnitude and statistical significance, stronger expressed over Bulgaria, rather than over the whole domain.

Evidently, longer TGS favors a greater diversity of crops, including those with long maturation periods, and the potential for multiple harvests on the same land. This lengthening is likely to contribute to increased biomass formation, which is part of a global increase in biospheric activity. Conversely, both irrigation needs and the risk from invasive species, pests, and pathogens may increase (Harding et al., 2015). The estimated changes of the TGS-related indicators could be a prerequisite for deep ecological and economical consequences. Subsequently, similar studies could be the methodologically reliable scientific basis of the long-range policy and expert assessments for managing systems as agriculture and forestry.

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References

Alexander, L. V., Zhang X., Peterson T. C., Caesar J., Gleason B., Klein Tank A., Haylock M., Collins D., Terwin B., Rahimzadeh F., Tagipour A., Ambenje P., Rupa Kumar K., Revadekar J., Griffiths G., Vincent L., Stephenson D., Burn J., Aguilar E., Brunet M., Taylor M., New M., Zhai P., Rusticucci M. & Vazquez-Aquirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research, 111*(D5). doi: 10.1029/2005jd006290.

Bartholy, J. & Pongracz, R. (2006). Comparing tendencies of some temperature related extreme indices on global and regional scales. *IDŐJÁRÁS 110*(1):35-48.

Birsan, MV., Dumitrescu, A., Micu, D. M. & Cheval, S. (2014). Changes in annual temperature extremes in the Carpathians since AD 1961, *Natural Hazards, 74*(1899). doi: 10.1007/s11069-014-1290-5.

Chervenkov, H., Slavov, K. & Ivanov, V. (2019). STARDEX and ETCCDI Climate Indices Based on E-OBS and CARPATCLIM; Part One: General Description, In Nikolov, G. et al. (Eds.): *NMA 2018*, LNCS 11189, (pp. 360-367). doi: 10.1007/978-3-030-10692-8_40.

Chervenkov, H. & Slavov, K. (2019). STARDEX and ETCCDI Climate Indices Based on E-OBS and CARPATCLIM; Part Two: ClimData in Use, In Nikolov, G. et al. (Eds.): *NMA 2018,* LNCS 11189, (pp. 368-374). doi: 10.1007/978-3-030-10692-8_41.

Chervenkov, H. & Slavov, K. (2020). Historical Climate Assessment of Temperature-based ETCCDI Climate Indices Derived from CMIP5 Simulations, *Comptes Rendus de l'Academie Bulgare des Sciences, 73*(6), 784-790. doi: 10.7546/CRABS.2020.06.05.

Chervenkov H. & Slavov K. (2021a). ETCCDI Climate Indices for Assessment of the Recent Climate over Southeast Europe. In Dimov, I. & Fidanova, S. (Eds.) Advances in High Performance Computing. HPC 2019. *Studies in Computational Intelligence, 902*, 398-412. Springer, Cham. doi: 10.1007/978-3-030-55347-0_34.

Chervenkov, H. & Slavov, K. (2021b) Assessment of agrometeorological indices over Southeast Europe in the context of climate change (1961–2018), *IDŐJÁRÁS 125*(2), 255–269. doi: 10.28974/idojaras.2021.2.5.

Chervenkov, H. & Slavov, K. (2022). Assessment of the Future Thermal Conditions over Europe based on CMIP5 Ensemble of Agro-meteorological Indices, *Bulgarian Journal of Agricultural Sciences.* (in press).

Cheval, S., Birsan, M.V. & Dumitrescu, A. (2014). Climate variability in the Carpathian Mountains region over 1961-2010. *Global*

Planet Change, 118, 85-96. 10.1016/j.gloplacha.2014.04.005.

Cornes, R., van der Schrier, G., van den Besselaar, E. J. M. & Jones, P. D. (2018). An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, *Journal of Geophysical Research and Atmosphere, 123.* doi: 10.1029/2017JD028200.

Harding, A. E., Rivington, M., Mineter M. J. & Tett S. F. B. (2015) Agro-meteorological indices and climate model uncertainty over the UK, *Climatic Change, 128,* 113–126. doi: 10.1007/s10584-014-1296-8.

Harkness, C., Semenov, M. A., Areal, F., Senapati, N., Trnka, M. & Balek, Bishop, J., (2020). Adverse weather conditions for UK wheat production under climate change, *Agricultural and Forest Meteorology, 282–283,* 107862. doi: 10.1016/j.agrformet.2019.107862.

Hatfield, J. L. & Prueger, J. H. (2011). Agroecology: Implications for Plant Response to Climate Change. In S. Yadav, R. J. Redden, J. L. Hatfield, H. LotzeCampen and A. E. Hall (Eds.), *Crop Adaptation to Climate Change,* (pp. 27–43). Wiley-Blackwell, West Sussex, UK.

Hatfield, J. L. & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development, *Weather and Climate Extremes, 10*(A), 4–10. doi: 10.1016/j.wace.2015.08.001.

Ivanov, V., Chervenkov, H., Gadzhev, G. & Ganev, K. (2020). Degree-Days And Agro-Meteorological Indices In Projected Future Climate Over Southeast Europe, *Proceedings of the 20th international multidisciplinary scientific geoconference SGEM 2020, 18-24, August, 20(4.1),* 373-380, doi: 10.5593/sgem2020/4.1/s19.047.

Lakatos, M., Szentimrey, T., Bihari, Z., Kovacs, T. & Szalai, S. (2013). Investigation of climate extremes in the Carpathian region on harmonized data. In Siska, B. et al. (Eds.). *Environmental changes and adaptation strategies,* Slovakia, Skalica, 9-11 September 2013.

Lakatos, M., Bihari, Z., Szentimrey, T., Spinoni, J. & Szalai, S. (2016). Analyses of temperature extremes in the Carpathian Region in the period 1961-2010, *IDŐJÁRÁS, 120*(1), 41-51.

Lavaysse, C., Camalleri, C., Dosio, A., van der Schrier, G., Toreti, A. & Vogt, J. (2017). Towards a monitoring system of temperature extremes in Europe, *Natural Hazards and Earth System Sciences,* 1-29. doi: 10.5194/nhess-2017-181.

Linderholm, H. W., (2006) Growing season changes in the last century. *Agricultural and Forest Meteorology, 137,* 1–14. doi: 10.1016/j.agrformet.2006.03.006.

Liu, Q., Fu, Y.H., Zhu, Z., Liu, Y., Liu, Z., Huang, M., Janssens, I.A. & Piao, S. (2016). Delayed autumn phenology in the Northern Hemisphere is related to change in both climate and spring phenology. *Global Change Biology, 22*: 3702-3711. doi: 10.1111/gcb.13311.

Luo, Q. (2011). Temperature thresholds and crop production: a review, *Climatic Change 109,* 583–598. doi: 10.1007/s10584-011-0028-6.

Menzel, A., Jakobi, G., Ahas, R., Scheifinger, H. & Estrella, N. (2003). Variations of the climatological growing season (1951–2000) in Germany compared with other countries. *International Journal of Climatology, 23,* 793-812. doi: 10.1002/joc.915.

Mesterhazy, I., Meszaros, R., Pongracz, R., Bodor, P. & Ladanyi, M. (2018). The analysis of climatic indicators using different growing season calculation methods – an application to grapevine grown in Hungary, *IDŐJÁRÁS 122*(3), 217–235.

Seemann, J., Chirkov, Y. I., Lomas, J. & Primault, B. (1979). *Agrometeorology,* Springer-Verlag Berlin Heidelberg New York, doi: 10.1007/978-3-642-67288-0.

Szyga-Pluta, K. & Tomczyk, A. M. (2019). Anomalies in the length of the growing season in Poland in the period 1966–2015, *IDŐJÁRÁS, 123*(3), 391–408. doi: 10.28974/idojaras.2019.3.8.

WMO. (2000). *Detecting Trend and Other Changes in Hydrological Data*. WCDMP-45, WMO/TD 1013.

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C., Trewin, B. & Zwiers, F.W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. *WIREs Clim Change, 2,* 851–870. doi: 10.1002/wcc.147.

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