Changes in the climatic growing season in western Anatolia, Turkey

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Abstract
In this study spatial and temporal variations of climatic growing season parameters in western Anatolia, Turkey, during 1966–2015 are analysed. The beginning of the growing season (end of the growing season) for all threshold values of 5, 7 and 10°C is delayed (advances) from the southwest to the northeast over the study area. The growing season length (GSL) increases from northeast to southwest. The growing season start (GSS), growing season end (GSE) and GSL are strongly correlated with elevation, low-elevation stations having earlier GSS, later GSE and longer GSL than stations at higher elevations. The regional average GSS shifted 7.3, 10.0 and 10.5 days earlier, while the regional average GSE moved 4.8, 6.1 and 6.2 days later, increasing the GSL by 12.0, 16.6 and 15.9 days for 5, 7 and 10°C, respectively. A comparison of mean values between subperiods documented significant changes at more than 50% of stations for GSS and GSL from the subperiod 1977–1997 to the subperiod 1998–2015 and almost no significant change between 1966–1976 and 1977–1997 for all thresholds. Correlation analysis showed that the East Atlantic Pattern was the main driver for GSS and the North Sea–Caspian Pattern for GSE, followed by the East Atlantic/Western Russia Pattern and the North Atlantic Oscillation, respectively. Monthly and annual precipitation totals and precipitation distribution within a year have not changed significantly, suggesting that air temperature has become more influential on GSS and GSE.

KEYWORDS
global warming, growing season parameters, trend analysis, western Anatolia

1 INTRODUCTION

One of the consequences of climate change is related to the changes in growing season parameters (GSPs) (start, end and length). In a warmer environment, GSPs are expected to be different from before. Thus, the changes in GSPs can be considered as an important indicator of climate change and have important implications for ecosystems (Robeson, 2002), as organisms respond to growing season changes, e.g. to an earlier start of the growing season by migrating earlier (birds, insects, mammals), emerging from dormancy earlier (mammals, insects), developing new leaves and stems earlier (plants) and breeding earlier (mammals, insects, birds, plants), and to
a later end of the growing season by shedding leaves later (deciduous trees) and migrating later (birds, mammals) (Haggerty and Mazer, 2008). Intensifying studies within the last decade in various parts of the world to understand and quantify the GSP changes in response to global warming report that there have been an earlier growing season start (GSS) and a later growing season end (GSE), and hence a lengthening of the growing season, e.g. in China (Liu et al., 2010; Jiang et al., 2011; Dong et al., 2013; Cui et al., 2018), in Poland (Graczyk and Kundzewicz, 2016; Tomczyk and Szyga-Pluta, 2019), in Germany (Menzel et al., 2003), in the United States (Robeson, 2002) and in the Greater Baltic Area (Walther and Linderholm, 2006).

The growing season length (GSL) is the number of days when plant growth occurs in a given region. GSL is often considered when determining which crops can be grown in an area since some crops mature slowly while others require short growing seasons. GSL is influenced by many different factors such as air temperature, frost days, rainfall or daylight hours subject to the region and the climate (EPA, 2016). GSL has a strong effect on ecosystem function (White et al., 1999). GSP variations due to climate change are also influential in the field of agriculture and forestry. In some regions, such as high northern latitudes, an extended GSL with a warmer growing season would create more favourable climatic conditions for crops at present grown in more southern regions (Wielgolaski, 2003; ACIA, 2004; Song et al., 2010). While an extended GSL could allow farmers to grow more diversified crops or have more than one harvest from the same land, the types of crops grown could be limited, invasive species encouraged and weed control could become difficult (EPA, 2016). Also, it may affect the hydrological cycle, leading to an increase in evapotranspiration and a decrease in soil moisture and streamflow (Backlund et al., 2008; Christiansen et al., 2011).

The influence of climate change on GSPs can be analysed by means of phenological observations, climatic data and remote sensing based observations (Liu et al., 2010). The dates of occurrence of plant phenotheses (such as bloom, bud-burst, leaf unfolding, defoliation and leaf colouration) observed from individual species is used to determine GSPs (Liu et al., 2010). Although this metric provides high quality data and facilitates the quantification of plant responses to climate, observations are laborious and time consuming and would be available for a limited geographic area and/or individuals (Richardson et al., 2009; Shen et al., 2012). Another way to estimate GSL is the use of remote sensing data obtained via sensors on satellites. These kinds of data provide information about growth phases of vegetation within the year (Vrieling et al., 2013). The growing season can also be defined based on climatic observations. Since temperature is an important factor for plant growth, a number of temperature-derived indices can be considered as indirect indicators of growing conditions of plants (Liu et al., 2010). In addition to its low data requirement, this approach is straightforward and less time consuming. Also, widespread and long term availability of temperature records make it possible to analyse the evolution of GSPs under a changing climate. However, no universal definition of GSPs is available, possibly due to regional differences in climatic conditions associated with the growing season (Walther and Linderholm, 2006). The climatic or thermal growing season is defined as the whole period in which plant growth can theoretically occur; it does not represent the actual growth period (Linderholm et al., 2008).

In the present study, the objective was to analyse the spatial distribution of the mean values of climatic GSPs and the long term monotonic temporal variation of annual GSP time series during 1966–2015 for the 5, 7 and 10°C thresholds over western Anatolia, Turkey. The variations of the climatic (or thermal) growing season have not been investigated for all or any part of Turkey. It is expected that the results will be a fundamental resource for agricultural researchers. In addition, the results will reveal how the GSPs over the study area are affected by climate change. The results will be indicative for the assessment of the problems/opportunities that may arise in the context of climate change.

2 MATERIALS AND METHODS

The study area encompasses, completely or partially, 12 provinces located in western Anatolia, Turkey, with a total area of about 130,000 km². It extends from latitude 36 °N to 42 °N and from longitude 26 °E to 30 °E and is limited by the Mediterranean Sea in the south, the Marmara Sea in the north and the Aegean Sea in the west (Figure 1). It is mainly under the influence of a Mediterranean climate, with hot and dry summers and mild and rainy winters.

Daily minimum (T_{\text{min}}) and maximum (T_{\text{max}}) temperature data of 35 weather stations located in western Turkey for the period 1966–2015 were obtained from the State Meteorological Service of Turkey. The list of stations is given in Table 1, and the locations of the stations in the study area are shown in Figure 1. Daily mean temperatures were calculated by averaging daily T_{\text{min}} and T_{\text{max}}. Daily T_{\text{min}} and T_{\text{max}} data were subjected to a careful quality control procedure to detect missing data and to verify that daily T_{\text{max}} was greater than daily T_{\text{min}} (Hu et al., 2012). Annual mean series of T_{\text{max}} and T_{\text{min}}
were examined for homogeneity using the double mass curve method (Tabari and Hosseinzadeh Talaei, 2011; Hu et al., 2012).

No universal definition of GSPs is available (Walther and Linderholm, 2006). Among various definitions, those given by Menzel et al. (2003) were employed in this study. GSS is the first day of the period when the daily mean temperature is constantly equal to or greater than the threshold temperature and does not fall below the threshold temperature again. GSE is the last day of the period when the daily mean temperature is constantly equal to or greater than the threshold temperature and does not fall below the threshold temperature again. GSL is the period between GSS and GSE. Three threshold temperatures, 5, 7 and 10°C, were used as recommended by Menzel et al. (2003). Where appropriate for simplicity, combinations of GSPs and thresholds are shown as a GSP symbol (i.e. GSS, GSE and GSL) followed by a threshold, e.g. GSS 5 stands for GSS for the 5°C threshold throughout the paper.

GSPs were calculated for each year at each station and then averaged over the study period to obtain their long term mean values for any station. The inverse distance weighted interpolation method was used to depict the spatial pattern of long term mean values of GSPs over the study area in a simple way.

The influences of large-scale circulation patterns on GSPs were examined for each station over the study area. These patterns are the North Atlantic Oscillation (NAO), Mediterranean Oscillation (MO), East Atlantic Pattern (EA), Western Mediterranean Oscillation (WEMO), East Atlantic/Western Russia Pattern (EA/WR), Pacific Decadal Oscillation (PDO), North Sea–Caspian Pattern (NCP) and El Niño Southern Oscillation (ENSO). Two versions of the MO were considered. One is defined as the normalized pressure difference between Algiers and
Cairo (MO_AC). The second version is calculated from Gibraltar’s Northern Frontier and Lod Airport in Israel (MO_GI). Monthly index values of these patterns were obtained from the following sources: NAO, EA, EA/WR, ENSO from the National Oceanic and Atmospheric Administration (https://www.cpc.ncep.noaa.gov/data/teledoc/teleintro.shtml and https://www.esrl.noaa.gov), MO_AC, MO_GI, WEMO and NCP from the Climatic Research Unit of the University of East Anglia (https://crudata.uea.ac.uk/cru/data/pci.htm) and the PDO from the University of Washington (http://research.jisao.washington.edu/pdo/PDO.latest.txt). Monthly index values were averaged to obtain mean values from January through April and from October through December for searching their influence on GSS and GSE, respectively, by means of Pearson correlation. The idea behind obtaining index averages over the periods January–April and October–December is that most of the GSSs and GSEs respectively occurred within these periods during 1966–2015. The significance level for assessing the correlations was 5%.

The start, end and length of growing season are also controlled by precipitation. In addition to precipitation amount, any change in the distribution of precipitation within a year over a period of time is also important for assessment of GSP changes. Various indices such as the precipitation concentration index (PCI), proposed originally by Oliver (1980) and modified by De Luís et al. (1997), the precipitation concentration degree (PCD) and the precipitation concentration period (PCP), proposed by Zhang and Qian (2003), are widely used indices to assess precipitation distribution within a year. In a previous study, Yeşilirmak and Atatanır (2016) detected no overall significant monotonic trends in these indices during the period 1966–2011 at 28 stations over the same area. In this study, precipitation data were updated adding more recent data (after 2011) and seven more stations. Then, indices and their monotonic trends were recalculated. Details of the methods for calculation of the indices are given in Yeşilirmak and Atatanır (2016).

The non-parametric Mann–Kendall test and Sen’s slope estimator were employed to detect statistical significance and magnitude of trends in time series, respectively, by using the Excel template MAKESENS (Mann–Kendall test for trend and Sen’s slope estimates) developed by Salmi et al. (2002). In the Mann–Kendall test, the null hypothesis of no trend (H0) is that the observations \( x_i \) are randomly ordered in time. The alternative hypothesis (H1) states that there is an increasing or decreasing linear trend. The Mann–Kendall test statistic \( S \) is calculated using the formula:

\[
S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k)
\]

where \( x_j \) and \( x_k \) are the values in years \( j \) and \( k \), respectively, and

| TABLE 1 | Details of the stations |
|----------|------------------------|
| Station  | Latitude (° N) | Longitude (° E) | Elevation (m above sea level) |
| Akhisar   | 38.9118 | 27.8233 | 92 |
| Aydın     | 37.8402 | 27.8739 | 57 |
| Ayvalik   | 39.3113 | 26.6861 | 4 |
| Bandırma  | 40.3315 | 27.9965 | 63 |
| Bergama   | 39.1098 | 27.1710 | 53 |
| Bodrum    | 37.0328 | 27.4398 | 26 |
| Burdur    | 37.7220 | 30.2940 | 957 |
| Bursa     | 40.2308 | 29.0133 | 100 |
| Çanakkale | 40.1410 | 26.3993 | 6 |
| Çeşme     | 38.3036 | 26.3724 | 5 |
| Datça     | 36.7083 | 27.6919 | 28 |
| Denizli   | 37.7620 | 29.0921 | 425 |
| Dikili    | 39.0737 | 26.8880 | 3 |
| Dursunbey | 39.5778 | 28.6322 | 637 |
| Edremit   | 39.5895 | 27.0192 | 21 |
| Elmalı    | 36.7372 | 29.9121 | 1,095 |
| Fethiye   | 36.6266 | 29.1238 | 3 |
| Finike    | 36.3024 | 30.1458 | 2 |
| Güney     | 38.1515 | 29.0587 | 825 |
| İzmir     | 38.3949 | 27.0819 | 29 |
| Keles     | 39.9150 | 29.2313 | 1,063 |
| Köyceğiz | 36.9700 | 28.6869 | 24 |
| Kuşadası  | 37.8597 | 27.2652 | 25 |
| Kütahya   | 39.4171 | 29.9891 | 969 |
| Manisa    | 36.6153 | 27.4049 | 71 |
| Milas     | 37.3027 | 27.7804 | 57 |
| Muğla     | 37.2095 | 28.3668 | 646 |
| Nazilli   | 39.9135 | 28.3437 | 84 |
| Ödemiş    | 38.2157 | 27.9642 | 111 |
| Salihli   | 38.4831 | 28.1234 | 111 |
| Selçuk    | 37.9445 | 27.3673 | 17 |
| Simav     | 39.0925 | 28.9786 | 809 |
| Tavşanlı  | 39.5384 | 29.4941 | 833 |
| Tefenni   | 37.3161 | 29.7792 | 1,142 |
| Uşak      | 38.6712 | 29.4040 | 919 |
\[
\text{sgn}(x_j - x_k) = \begin{cases} 
1 & \text{if } x_j - x_k > 0 \\
0 & \text{if } x_j - x_k = 0 \\
-1 & \text{if } x_j - x_k < 0 
\end{cases}
\tag{2}
\]

If the number of values in the series denoted by \( n \) is 9 or less, the absolute value of \( S \) is compared directly to the theoretical distribution of \( S \) derived by Mann and Kendall (Gilbert, 1987). If \( n \) is at least 10, the normal approximation test is used. For doing this, first the variance of \( S \) is calculated using the following equation which takes into account ties, if they exist:

\[
\text{VAR}(S) = \frac{1}{18} \left[ n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1) (2t_p + 5) \right]
\tag{3}
\]

where \( q \) is the number of tied groups and \( t_p \) is the number of data values in the \( p \)th group. Then, the test statistic \( Z \) is calculated using \( S \) and \( \text{VAR}(S) \) as follows:

\[
Z = \begin{cases} 
\frac{S - 1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 
\end{cases}
\tag{4}
\]

A positive (negative) value of \( Z \) indicates an upward (downward) trend. The statistic \( Z \) has a normal distribution. To decide if there is a statistically significant linear trend (a two-tailed test) at the \( \alpha \) level of significance, \( H_0 \) is rejected if the absolute value of \( Z \) is greater than \( Z_{1-\alpha/2} \), where \( Z_{1-\alpha/2} \) is obtained from the standard normal cumulative distribution tables. In this study, a significance level of \( \alpha = 0.05 \) was used.

The trend magnitudes (\( \beta \)) were determined using the following equation (Sen’s slope estimator):

\[
\beta = \text{median} \left( \frac{x_j - x_i}{i - j} \right) \quad \forall j < i
\tag{5}
\]

If there was autocorrelation within any GSP series, an approach known as trend-free prewhitening (TFPW) was applied (Yue et al., 2002). According to Yue et al. (2002), the TFPW procedure is applied as follows:

1. Remove the linear trend from the original series.
2. Estimate the lag – 1 serial correlation within the detrended series.
3. If the lag – 1 serial correlation is not statistically significant at the 95% level, then trend analysis is applied to the original series.
4. If the lag – 1 serial correlation is statistically significant, remove the serial correlation.
5. Add the removed trend at the first step to the prewhitened series and obtain a new series.
6. Apply trend analysis to the new series.

On the other hand, prewhitening is not recommended depending on the coefficient of variation, trend rate and sample size, e.g. when the coefficient of variation is very low (\( C_v = 0.1 \)) for all sample sizes (Bayazit and Önöz, 2007). Following the suggestions made by Yue et al. (2002) and Bayazit and Önöz (2007), only 13 series needed the TFPW procedure: the GSS 5 series at Uşak, Tavşanlı, Kütahya; GSS 7 series at Keles; GSS 10 series at Tavşanlı, Selçuk, Simav, Kütahya and Bodrum; GSE 7 series at Denizli; GSL 5 series at Tavşanlı; and GSL 10 series at Bodrum and Datça.

3 | RESULTS AND DISCUSSION

3.1 | Spatial variations of mean values of GSPs

Figure 2 presents the spatial distributions of averaged GSS, GSE and GSL for the thresholds 5, 7 and 10°C during 1966–2015 over the study area. There exists an obvious increasing (decreasing) gradient from southwest to northeast for GSS (GSE and GSL) for all thresholds. While the earliest (latest) GSSs (GSEs) occur at the stations located in the southern and southwestern parts of the study area, the latest (earliest) GSSs (GSEs) occur in the northeastern part. Hence, GSL increases from northeast to southwest, i.e. from the locations with later start and earlier end to the locations with earlier start and later end. Regional mean values for GSS (GSE) are the 63rd (339th), 79th (328th) and 100th (313th) days of the year (DOY) for 5, 7 and 10°C, respectively. The corresponding values for GSL are 276, 250 and 212 days. The extreme cases occurred at the southernmost and the northernmost stations. As an example, for the threshold 5°C, there were never-ending growing seasons at Finike, Datça and Bodrum; and Keles had the extreme latest GSS (133rd DOY in 1986), the earliest GSE (271st DOY in 1970) and the shortest GSL (159 days in 1989).

The results show also the influences of latitude and elevation on GSPs (Figures 1–3). As expected, stations with lower elevation/latitude have earlier GSS, later GSE
and longer GSL. For example, the stations with lower lat-itude such as Burdur, Elmali and Tefenni have later (ear-
lier) GSS (GSE) and shorter GSL than those with approximately the same latitudes as a consequence of their higher elevations. As well as the extreme cases observed in individual years, Keles also has the highest/lowest averages as it is located at the highest elevation among the northernmost stations. A similar result was reported by Zhu et al. (2019) for Qinghai-Tibetan Plateau. They found that elevation was the dominant influencing factor of the spatial variations of GSS and that the effect of latitude was more important in the low-elevation
regions, especially for the GSS with a low-temperature threshold (e.g. GSS for 0°C).

### 3.2 Temporal variations of GSP

The spatial distributions of GSS, GSE and GSL trends and their magnitudes for the thresholds 5, 7 and 10°C during 1966–2015 over the study area are shown in Figure 4 and tabulated in Table 2, respectively. The results display a general decreasing (increasing) trend for GSS (GSE). The number of significant changes differs between the thresholds. It follows that there have been earlier (later) occurrences of GSS (GSE) over the study period. In terms of regional averages, GSS (GSE) has shifted 7.3 (4.8) days, 10.0 (6.1) days and 10.5 (6.2) days to an earlier (a later) date for 5, 7 and 10°C, respectively. A decreased GSS and an increased GSE suggest an increased GSL. Thus, GSL has extended, on average, 12.0 days for 5°C, 16.6 days for 7°C and 15.9 days for 10°C over the study period.

The results of this study are in good agreement with those of previous studies in terms of directions of trends. However, the magnitudes of the trends differ due to the different definitions for climatic GSPs and/or the spatial inhomogeneity of global warming. In Germany, Menzel et al. (2003) reported that GSL extended by 0.11–0.49 days per year during 1951–2000, depending on the criteria analysed. Tomczyk and Szyga-Pluta (2019) detected increases in GSE and GSL and decreases in GSS in Poland over the period 1966–2015. Similar results were also obtained for Poland by Graczyk and Kundzewicz (2016), where increases in the lengths of the growing season and the frost-free season and decreases in the date of occurrence of last spring frost were observed during 1951–2010. A similar research in Illinois, United States, showed that GSL has become roughly 7 days longer during the 20th Century (Robeson, 2002). Dong et al. (2013) found that climatic GSL in northeast China extended by 13.3 days during 1960–2009. For the whole of China, GSS advanced by 4.86–6.71 days and GSE was delayed by 4.32–6.19 days, lengthening the growing season by 10.76–11.02 days over the period 1960–2011, depending on the threshold level (Yin et al., 2019).
The increase of GSL is the result of both an earlier occurrence of GSS and a later occurrence of GSE. However, it is mostly attributed to advances in GSS rather than delays in GSE (Menzel et al., 2003). Similarly, in the present study, GSS for the 5, 7 and 10°C thresholds has become earlier by 7.3, 10.0 and 10.5 days, respectively, and GSE has occurred later by 4.8, 6.1 and 6.2 days, respectively. A similar result was found in the research for the Greater Baltic Area by Walther and Linderholm (2006). They reported that the average start of the growing season

**FIGURE 4** The spatial distributions of GSS, GSE and GSL trends
TABLE 2  The magnitudes of trends (day-year$^{-1}$) in GSS, GSE and GSL for thresholds of 5, 7 and 10°C during 1966–2015 over the study area

| Station        | GSS (day-year$^{-1}$) | GSE (day-year$^{-1}$) | GSL (day-year$^{-1}$) |
|----------------|-----------------------|-----------------------|-----------------------|
|                | 5°C       | 7°C       | 10°C      | 5°C       | 7°C       | 10°C      | 5°C       | 7°C       | 10°C      |
| Akhisar        | −0.39     | −0.09     | −0.29     | 0.23      | 0.07      | 0.30      | 0.55      | 0.19      | 0.61      |
| Aydın          | −0.11     | −0.50     | −0.26     | 0.13      | 0.24      | −0.06     | 0.24      | 0.68      | 0.27      |
| Ayvalik        | −0.18     | −0.15     | −0.06     | 0.03      | 0.19      | 0.06      | 0.23      | 0.36      | 0.00      |
| Bandırma       | −0.07     | −0.08     | −0.14     | 0.13      | 0.00      | 0.00      | 0.19      | 0.09      | 0.07      |
| Bergama        | −0.39     | −0.03     | −0.21     | 0.19      | 0.08      | −0.04     | 0.49      | 0.20      | 0.21      |
| Bodrum         | 0.00      | −0.11     | −0.31     | 0.00      | 0.00      | 0.2       | 0.00      | 0.14      | 0.58      |
| Burdur         | −0.11     | −0.27     | −0.22     | 0.00      | 0.03      | 0.15      | 0.10      | 0.28      | 0.33      |
| Bursa          | −0.07     | −0.14     | 0.00      | 0.14      | 0.00      | 0.11      | 0.08      | 0.10      | 0.15      |
| Çanakkale      | −0.14     | −0.14     | 0.00      | 0.16      | 0.11      | 0.06      | 0.33      | 0.20      | 0.16      |
| Çeşme          | 0.00      | −0.08     | −0.14     | 0.00      | 0.00      | 0.17      | −0.03     | 0.12      | 0.31      |
| Datça          | 0.00      | 0.00      | −0.01     | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.28      |
| Denizli        | −0.21     | −0.25     | −0.40     | 0.32      | 0.21      | 0.21      | 0.40      | 0.53      | 0.62      |
| Dikili         | −0.14     | −0.14     | −0.18     | 0.00      | 0.18      | −0.05     | 0.15      | 0.33      | 0.15      |
| Dursunbey      | −0.13     | −0.14     | −0.11     | −0.08     | 0.13      | 0.14      | 0.05      | 0.30      | 0.14      |
| Edremit        | −0.33     | −0.23     | −0.10     | 0.20      | 0.25      | 0.15      | 0.56      | 0.46      | 0.20      |
| Elmalı         | −0.18     | −0.33     | −0.21     | 0.14      | 0.23      | 0.23      | 0.37      | 0.50      | 0.45      |
| Fethiye        | 0.00      | −0.44     | −0.40     | 0.00      | 0.00      | 0.33      | 0.03      | 0.59      | 0.63      |
| Finike         | 0.00      | 0.00      | −0.28     | 0.00      | 0.00      | 0.18      | 0.00      | 0.07      | 0.48      |
| Güney          | −0.16     | −0.36     | −0.04     | 0.23      | 0.13      | −0.05     | 0.43      | 0.40      | −0.06     |
| İzmir          | −0.23     | −0.31     | −0.16     | −0.02     | 0.27      | 0.00      | 0.10      | 0.64      | 0.13      |
| Keles          | 0.03      | −0.14     | −0.39     | −0.08     | 0.08      | 0.05      | −0.07     | 0.10      | 0.47      |
| Köyceğiz       | 0.00      | 0.02      | −0.03     | 0.00      | 0.00      | 0.03      | −0.07     | 0.00      | 0.05      |
| Kuşadası       | −0.38     | −0.46     | −0.44     | 0.29      | 0.23      | 0.19      | 0.71      | 0.70      | 0.67      |
| Kütahya        | −0.11     | −0.03     | −0.15     | 0.00      | 0.18      | 0.12      | 0.27      | 0.17      | 0.18      |
| Manisa         | −0.31     | −0.12     | −0.23     | 0.12      | 0.03      | 0.07      | 0.36      | 0.09      | 0.29      |
| Milas          | 0.00      | −0.22     | −0.36     | 0.00      | 0.28      | 0.15      | 0.05      | 0.50      | 0.58      |
| Muğla          | −0.13     | −0.16     | −0.25     | 0.29      | 0.00      | 0.18      | 0.41      | 0.22      | 0.43      |
| Nazilli        | 0.11      | −0.08     | −0.15     | 0.05      | 0.20      | −0.07     | 0.04      | 0.21      | 0.00      |
| Ödemiş         | 0.00      | −0.20     | −0.33     | 0.19      | 0.13      | 0.13      | 0.25      | 0.26      | 0.39      |
| Salihli        | −0.35     | −0.20     | −0.15     | 0.20      | 0.09      | 0.29      | 0.60      | 0.30      | 0.31      |
| Selçuk         | −0.38     | −0.30     | −0.47     | 0.21      | 0.191     | 0.15      | 0.56      | 0.45      | 0.56      |
| Simav          | −0.28     | −0.29     | −0.17     | 0.03      | 0.14      | 0.17      | 0.33      | 0.48      | 0.24      |
| Tavşanlı        | −0.24     | −0.24     | −0.15     | −0.06     | 0.27      | 0.11      | 0.26      | 0.64      | 0.20      |
| Tefenni        | −0.13     | −0.33     | −0.11     | 0.15      | 0.17      | 0.18      | 0.28      | 0.50      | 0.27      |
| Uşak           | −0.13     | −0.24     | −0.19     | 0.17      | 0.00      | 0.17      | 0.31      | 0.36      | 0.33      |

Statistically significant trends at the 95% level are shown in bold.

1) GSL (day-1)

shifted 12 days earlier while the average end moved 8 days later, increasing the length of the growing season by 20 days. Tomczyk and Szyga-Pluta (2019) found that a decrease of GSS had more influence on increasing GSL than an increase of GSE in Poland, as the GSE had a slower rate of change than GSS. In contrast, Jiang et al. (2011) found that the increase in GSL in Xinjiang province, northwest China, during the period 1959–2008 was attributed mainly to the delay of GSE (2.5 days-decade$^{-1}$) rather than the advance of GSS (−1.0 days-decade$^{-1}$).
Depending on the temperature threshold index used, large differences could be observed in GSL trends. For instance, Brinkmann (1979) compared time series of the length of differently defined growing seasons at four Wisconsin stations, United States, and reported that the trend in GSL was sensitive to the particular definition used. In the present study, the difference between the GSL for thresholds 7 and 10°C is negligible (less than 1 day). However, the difference between 5°C and the other thresholds is remarkable (about 5 days).

3.3 Changes in GSPs between subperiods

The whole study period 1966–2015 was divided into three subperiods (1966–1976, 1977–1997 and 1998–2015), and then the changes in mean values of GSPs between successive periods were examined by t test at the 95% level: 1997–1977 versus 1966–1976 and 1998–2015 versus 1977–1997. This partition is based on the evolution of global mean temperatures, i.e. the decline from mid-20th Century to mid-1970s, the accelerated increase afterwards and the period after 1998 in which the rate of global warming has decreased in intensity, called the “warming hiatus” (Gonzalez-Hidalgo et al., 2016; Meehl, 2015). Among the hypotheses proposed to explain the hiatus are the decrease in stratospheric water vapour content, the heat redistribution between upper and lower oceanic layers, particularly in the Pacific, the combination of internal climate variability and radiative forcing, including anthropogenic factors (Gonzalez-Hidalgo et al., 2016), the prolonged minimum in the 11 year solar cycle, and volcanic eruptions (Meehl, 2015). According to Karl et al. (2015), “the supposed warming ‘hiatus’ is just an artifact of earlier analyses.” Additionally, Lewandowsky et al. (2016) stated that the latest warming hiatus is not unusual and that linear increases in CO₂ do not produce linear trends in global warming. After 2012, with the warmest years on record, it is thought that the global warming hiatus has ended (Zhang et al., 2019).

Noting that proving or disproving the existence of any warming hiatus after 1998 is not the objective of this study, the results show that almost no statistically significant change in mean values was detected between the periods 1977–1997 and 1966–1977, but many significant and strong changes were detected between the periods 1998–2015 and 1977–1997 (Figure 5). In terms of regional averages, GSS was 7.1, 7.7 and 8.9 days earlier, GSE was 4.0, 5.5 and 5.9 days later and GSL was 9.9, 13.1 and 15.9 days longer during the period 1998–2015 than the period 1977–1997 for 5, 7 and 10°C, respectively. It follows that global warming, with the years 2014 and 2015

![Figure 5](image-url)  The changes in mean values of GSS, GSE and GSL between subperiods
being among the warmest years on record (Zhang et al., 2019), has manifested itself as a significant impact on GSPs over western Anatolia between 1998 and 2015.

3.4 Association with teleconnection patterns

The relationships between GSS and GSE and selected teleconnection patterns were also examined to determine any possible influence of the patterns on the occurrence dates of GSS and GSE. Since GSL is controlled by GSS and GSE, its relationship with the patterns was not considered. As the majority of GSSs occur during the period January through April and GSEs during the period October through December, monthly values of the teleconnection indices were averaged to obtain their January–April and October–December mean values. Then, January–April mean values were correlated with GSSs and October–December mean values with GSEs.

Table 3 presents the number of stations with significant correlations (either positive or negative) between GSS and GSE and selected teleconnection indices for all thresholds. The total number of stations with significant correlation for all thresholds implies that EA (NCP) has the highest influence on GSS (GSE), followed by EA/WR

| Teleconnection | GSS 5 | GSS 7 | GSS 10 | GSE 5 | GSE 7 | GSE 10 |
|----------------|-------|-------|--------|-------|-------|--------|
| MO_AC          | 1     | 2     | 6      | 2     | 4     | 3      |
| NAO            | 0     | 1     | 2      | 4     | 5     | 6      |
| EA             | 14    | 15    | 3      | 5     | 4     | 1      |
| WEMO           | 4     | 3     | 1      | 1     | 4     | 2      |
| EAWR           | 15    | 7     | 0      | 1     | 5     | 7      |
| MO_GI          | 0     | 0     | 1      | 0     | 1     | 2      |
| PDO            | 3     | 5     | 7      | 0     | 0     | 0      |
| NCP            | 12    | 3     | 2      | 9     | 15    | 20     |
| ENSO           | 3     | 10    | 8      | 0     | 1     | 1      |

**FIGURE 6** Correlations between GSS and EA and between GSE and NCP
The correlations between EA (NCP) and GSS (GSE) were examined in more detail, and the coefficients are given on a map in Figure 6. The EA is negatively correlated with GSS at almost all stations. Significant correlations concentrate in the western half of the study area. The NCP also displays negative correlations with GSE at almost all stations. The most significant correlations are in the eastern half of the study area for 5 and 7°C but scattered over the whole area for 10°C. These results are not unexpected as various previous studies have well documented the association between air temperatures in Turkey and surrounding regions (i.e. the Balkan peninsula, Mediterranean basin and the Middle East) with the EA and NCP, and also with the EA/WR and the NAO (e.g. Türkes and Erlat, 2009; Toreti et al., 2010; Efthymiadis et al., 2011; Kahya, 2011; Lopez-Moreno et al., 2011; Ruml et al., 2017; Sezen and Partal, 2017; Scorzini and Leopardi, 2019).

3.5 Precipitation variability

The starting date, ending date and the length of the growing season are not only influenced by air temperature but also controlled by precipitation. The influence of precipitation was assessed both spatially and temporally.

The study area receives, in general, precipitation of more than 500 mm annually, even as much as 1,150 mm at the southwestern part (Figure 7). The wettest months are December, January and February, and a major portion of annual precipitation falls in late autumn, winter and early spring (Figure 8). It follows that the start and end of the growing season is controlled by temperature rather than precipitation as a result of the availability of precipitation in late autumn, winter and early spring, in which climatic GSS and GSE occur. On the other hand, the low-precipitation period from May to September (less than 100 mm in total during this period), together with higher temperatures, restrict vegetation growth. During this period, under water-limited conditions, vegetation growth is controlled by precipitation rather than temperature.

The southern and southwestern parts attract a special attention with regard to their relatively higher amount of annual precipitation and longer GSL. As a major portion of annual precipitation falls in late autumn, winter and early spring, the relatively earlier occurrences of GSS and later occurrences of GSE allow these parts to benefit from a very significant portion of annual total precipitation during the growing season. This makes these parts of the study area considerably more suitable for vegetation growth. For example, the province Muğla, which includes the stations Muğla, Datça, Bodrum, Fethiye, Köyceğiz and Milas within its administrative boundaries, is characterized by the highest amount of precipitation in the study area (Figures 7 and 8), relatively longer GSL (Figure 2) and larger extent of its forest land. Forests
cover 68% of its land surface. This is the second highest percentage among all provinces in Turkey (OGM, 2019).

The control of precipitation in the growing season was assessed in the temporal dimension by examining not only trends of monthly/annual precipitation totals but also those of various precipitation distribution indices (Table 4). In terms of the annual total precipitation, no statistically significant trend was detected at any station. Among the 420 station–month combinations (35 stations ×12 months), in only nine cases were trends significant. These results suggest statistically no overall change in the total amounts of precipitation in the study area, either monthly or annually. Not only precipitation amount but also distribution of precipitation within a year could be affected by climate change (De Luís et al., 2000; Li et al., 2011), and any change in the distribution could be influential on the growing season. The PCP, PCD and PCI based monthly data are useful indices to assess such shifts. The PCI, evaluates the distribution of monthly precipitation over the year. The PCD depicts the degree to which total annual precipitation is distributed over 12 months, whereas the PCP represents the period (month) in which total annual precipitation is concentrated (Zhang and Qian, 2003; Li et al., 2011). Yesilirmak and Atatanır (2016) detected no overall significant trends in these indices during the period 1966–2011 over the same area at 28 stations all of which are included in this study. In this study, precipitation data were updated by adding more recent data (after 2011) and seven more stations. Then, indices and their trends were recalculated. The results are almost the same: no overall significant trend with updated data (Table 4).

According to these findings, there have been no overall significant trends not only in amounts of monthly/annual precipitation but also in distribution of precipitation within a year. A number of previous studies also reported no overall changes in seasonal precipitation totals and strong temperature increases in summer over western Anatolia (Tayanç et al., 2009; Yeşilirmak, 2014; Hadi and Tombul, 2018). It follows that the start and end of the growing season have still been controlled by temperature, and that precipitation has had more control on vegetation growth during summer from 1966 to 2015 over the study area. Moreover, unchanged precipitation, increased evapotranspiration as a result of extended GSL, increased average temperatures (Backlund et al., 2008; Christiansen et al., 2011; Gaertner et al., 2019) and more likely extreme high temperature incidents would lead to more severe drought events and restrict vegetation growth particularly in the summer season over the study area.

### 4 | CONCLUSIONS

In terms of the long term mean values, the beginning (end) of the climatic growing season for all three threshold levels occurs later (earlier) from the southwest to the northeast, and climatic growing season length (GSL) increases from the northeast to the southwest over the study area. Growing season parameters (GSPs) are under the clear influence of both elevation and latitude. The stations located at higher latitudes/elevations have later starts, earlier ends and shorter lengths than those at lower latitudes/elevations.

There were overall increasing trends for growing season end (GSE) and GSL and decreasing trends for growing season start (GSS). In terms of regional averages, while GSS shifted to earlier dates by 7.3, 10.0 and 10.5 days, GSE shifted to later dates by 4.8, 6.1 and 6.2 days for 5, 7 and 10°C, respectively, over the period 1966–2015. These shifts resulted in 12.0 day (5°C), 16.6 day (5°C) and 15.9 day (5°C) longer durations in GSL. It follows that extensions in GSL are mostly due to the earlier occurrences of GSS. Similar results were found by many other studies for other parts of the world in

### TABLE 4 Number of stations with decreasing and increasing trends for monthly and annual precipitation totals, and for precipitation concentration period (PCP), precipitation concentration degree (PCD) and monthly precipitation concentration index (PCI)

| Period/index | Decreasing | Increasing | Period/index | Decreasing | Increasing |
|--------------|------------|------------|--------------|------------|------------|
| January      | 32 (0)     | 3 (0)      | September    | 20 (0)     | 15 (0)     |
| February     | 7 (0)      | 28 (0)     | October      | 4 (0)      | 31 (4)     |
| March        | 28 (0)     | 7 (0)      | November     | 10 (0)     | 25 (0)     |
| April        | 6 (0)      | 29 (0)     | December     | 31 (1)     | 4 (0)      |
| May          | 17 (0)     | 18 (0)     | Annual       | 17 (0)     | 18 (0)     |
| June         | 18 (1)     | 17 (0)     | PCP          | 21 (0)     | 14 (0)     |
| July         | 24 (2)     | 11 (0)     | PCD          | 35 (3)     | 0 (0)      |
| August       | 21 (1)     | 14 (0)     | PCI          | 22 (1)     | 13 (0)     |

The numbers in parentheses indicate the number of significant trends at the 95% level.
terms of directions of trends. However, the magnitudes of trends may differ depending on the definition of climatic growing season and on the spatial inhomogeneity of global warming.

The whole study period of 1966–2015 was divided into three subperiods, and then the changes in mean values of GSPs between the successive periods were examined (i.e. 1997–1977 versus 1966–1976 and 1998–2015 versus 1977–1997). This partition is based on the evolution of global mean temperatures from mid-20th Century, including the “warming hiatus” period between 1998 and 2012. In terms of averages, there were no changes in GSPs between the periods 1966–1976 and 1977–1997. On the other hand, when shifting from the period 1977–1997 to the period 1998–2015, more significant changes (earlier GSS, later GSE and longer GSL) were detected. It follows that global warming has a more pronounced impact on GSPs during the period 1998–2015 than the previous period over the study area.

The correlation analysis showed that the East Atlantic Pattern was the main driver for GSS and the North Sea–Caspian Pattern for GSE, followed by the East Atlantic/Western Russia Pattern and North Atlantic Oscillation, respectively. These results are in good agreement with the results of various previous studies as they well documented the association between these teleconnection patterns and air temperatures in Turkey.

Relatively higher amounts of precipitation in earlier and later months (from January to March and from October to December, respectively) of a year suggest that the start and end of the growing season is controlled by temperature rather than precipitation. On the other hand, vegetation growth during the mid-growing season from May to September is controlled by precipitation due to low precipitation and high temperatures in this period.

Southern and southwestern parts of the study area with earlier GSS and later GSE benefit from the considerable portion of total annual precipitation. This makes these parts more suitable for vegetation growth in comparison to other parts of the study area, as evidenced by higher forest cover than other parts (provinces) of the study area (Turkey).

Precipitation amount and precipitation distribution within a year have stayed unchanged over the study period, implying that the start and end of the growing season have still been controlled by temperature. However, the control of precipitation on vegetation growth during summer has been enhanced due to increased temperature and unchanged precipitation amount. Extended GSL accompanied by increased temperature would lead to an increase in evapotranspiration demand, and thereby to more severe drought events due to unsatisfied demand by precipitation.

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