Changes in the Local Growing Season in Eastern China during 1909−2012

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Abstract

The lack of long-term daily observations limited the study of changes in thermal growing season in China during the 20th century. Changes in the Local Growing Season (LGS) are analyzed based on a set of homogenized monthly temperature series back to the 19th century at 16 stations in eastern China. The analysis contains three steps: (1) to calculate the LGS indices (including the start and end dates) based on the daily temperature records at the 16 stations for the period 1960−2011; (2) to establish a linear relationship between the LGS indices and monthly temperature records; (3) to reconstruct the long-term LGS index series based on this linear relationship and the long-term monthly temperature records. It is found that, in eastern China, start (end) of LGS exhibits an advancing (a delaying) trend of −1.0 (0.5) days per decade, resulting in a lengthening trend of growing season of 1.5 days per decade, for the period 1909−2012. Changes in LGS indices are not monotonic but with multidecadal variability. In particular, enhanced LGS-lengthening trends occurred during 1910−1940 and 1965−2012. Especially from 1965 onward, the LGS has been significantly extended by 3.5 days per decade, of which about 35% is contributed from multidecadal variability.

1. Introduction

Growing season variability is an important climatic indicator, useful for a wide range of climatological and ecological applications (White et al. 1999; Robeson 2002; Linderholm 2006). In China, an increasing number of studies have reported on a late-twentieth century lengthening of growing season as evidenced in satellite data (Piao et al. 2005, 2006), phenological (Wang et al. 2012) and meteorological observations (Xu and Ren 2004; Liu et al. 2010; Song et al. 2010; Yang et al. 2013). The thermal growing season defined based on long time meteorological observations are often used taking advantage of fine spatial and temporal resolution. For example, Xu and Ren (2004) reported a country-averaged lengthening of thermal growing season with a rate of about 1.7 days per decade for the period 1961−2000. Liu et al. (2010) found that the growing season was extended by 1.5−1.9 days per decade for the period 1955-2000. Song et al. (2010) suggested rates of 1.3−2.3 days per decade of growing season lengthening in China for the period 1951−2007. For 1961−2007, the length of LGS was extended by 3.05 and 2.61 days per decade for base temperatures of 5°C and 10°C, respectively (Yang et al. 2013).

However, the changes in growing season for the whole 20th century in China has not been well studied yet. Previous regional studies (e.g., Carter (1998) for Nordic countries and Kunkel et al. (2004) for the United States) found that changes in growing season are not monotonic during the 20th century, showing multidecadal variability. China has experienced a significant warming trend during the 20th century, as well as multidecadal variability (Zhao et al. 2009). It can be inferred that the changes in growing season, which are strongly temperature-dependent, should also bear multidecadal variations during the 20th century. Yet this has not been well studied due to the lack of long-term daily observations.

Xia et al. (2013) found a good linear relationship between the start (end) date of local growing season (LGS, a definition made by Christidis et al. 2007) and the monthly mean temperature in April (October) by analyzing the global gridded daily temperature data for the period 1960−1999. This enabled them to reconstruct the time series of the LGS indices (start and end) over the world for the period 1901−2009, by using that linear relationship and monthly (April and October) mean temperature data. They then demonstrated multidecadal variations of LGS over the world. However, their results for the region of China remained problematic, because that global gridded dataset only contains instrumental observations in China before 1950. Recently, a set of long-term homogenized instrumental monthly mean surface air temperature series at 16 stations across eastern China back to the 19th century was developed (Cao et al. 2013). It enables a study of long-term LGS variations in China. The present study is to quantify the long-term variations of thermal growing season in China, hence putting the rapid changes in the recent decades into a historical perspective.

2. Data and methods

The homogenized monthly mean instrumental surface air temperature series back to the 19th century at 16 stations across eastern China (Table 1) are developed by Cao et al. (2013). The homogenized series of daily mean surface air temperature at the same 16 stations for the period 1960−2011 are updated from Li and Yan (2009), which are applied to calculate the linear relationship between the LGS indices and monthly temperature records. Besides, we apply the daily mean temperature series for the period 1873−2012 at Shanghai, which contains the early part up to 1960 homogenized by Yan et al (2001) and the late part for 1960−2012 homogenized by Li and Yan (2009).

LGS is defined using the local climatological annual mean temperature as the temperature threshold (Tm, Table 1) at a given station (Christidis et al. 2007). Following this, Tm is defined as the average temperature over the period 1960−2011 for each station in this study. For each year, the start (Ds) of LGS is the date when local temperature rises above Tm in the spring (in April) and the end (De) of LGS is the date when local temperature falls below Tm in the autumn (in October). We will investigate the long-term LGS variation following steps (1) to obtain the Ds and De time series for 1960−2011, by using the daily temperature records at each station; (2) to calculate the linear relationship between Ds and April temperature and that between De and October temperature (using the method developed by Xia et al. 2013), based on the daily dataset for 1960−2011; (3) to reconstruct the long-term (back to the 19th century) series of Ds and De, by using the linear relationship and monthly temperature at each station; and (4) to calculate the long-term variations of Ds and De.

Due to high frequency weather fluctuations, Ds and De as defined supra may not be unique in a year, if using raw daily temperature records. In response to this problem, the Ensemble Empirical Mode Decomposition (EEMD, Wu and Huang 2009) method is applied to obtain the temperature annual cycle without weather fluctuations. EEMD has advantage for uniquely determining Ds and De with minimal distortion to the original data.
Table 1. Station information for the 16 stations. ‘Tm’ is the local climatological annual mean temperature, e.g. the average temperature over the period 1960−2011 for each station. Average Ds/De over the same period for each station is also calculated and shown in Table 1.

<table>
<thead>
<tr>
<th>Number</th>
<th>Station</th>
<th>Starting Time (Year)</th>
<th>Tm (°C)</th>
<th>Average Ds</th>
<th>Average De</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hong Kong</td>
<td>1884</td>
<td>23.1</td>
<td>19 Apr</td>
<td>2 Nov</td>
</tr>
<tr>
<td>2</td>
<td>Macau</td>
<td>1901</td>
<td>22.0</td>
<td>17 Apr</td>
<td>1 Nov</td>
</tr>
<tr>
<td>3</td>
<td>Harbin</td>
<td>1909</td>
<td>−1.1</td>
<td>8 Apr</td>
<td>18 Oct</td>
</tr>
<tr>
<td>4</td>
<td>Harbin</td>
<td>1909</td>
<td>4.7</td>
<td>8 Apr</td>
<td>19 Oct</td>
</tr>
<tr>
<td>5</td>
<td>Hohehot</td>
<td>1915</td>
<td>7.1</td>
<td>7 Apr</td>
<td>17 Oct</td>
</tr>
<tr>
<td>6</td>
<td>Taiyuan</td>
<td>1916</td>
<td>10.5</td>
<td>7 Apr</td>
<td>14 Oct</td>
</tr>
<tr>
<td>7</td>
<td>Shenyang</td>
<td>1906</td>
<td>7.6</td>
<td>9 Apr</td>
<td>19 Oct</td>
</tr>
<tr>
<td>8</td>
<td>Beijing</td>
<td>1891</td>
<td>12.5</td>
<td>10 Apr</td>
<td>17 Oct</td>
</tr>
<tr>
<td>9</td>
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<td>1891</td>
<td>12.3</td>
<td>9 Apr</td>
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<td>10</td>
<td>Qingdao</td>
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<td>25 Apr</td>
<td>30 Oct</td>
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<tr>
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<td>16.2</td>
<td>14 Apr</td>
<td>19 Oct</td>
</tr>
<tr>
<td>12</td>
<td>Changsha</td>
<td>1911</td>
<td>17.4</td>
<td>17 Apr</td>
<td>21 Oct</td>
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<tr>
<td>13</td>
<td>Nanjing</td>
<td>1905</td>
<td>15.7</td>
<td>18 Apr</td>
<td>22 Oct</td>
</tr>
<tr>
<td>14</td>
<td>Shanghai</td>
<td>1873</td>
<td>16.6</td>
<td>25 Apr</td>
<td>28 Oct</td>
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<tr>
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<td>Fuzhou</td>
<td>1905</td>
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</tr>
<tr>
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<td>Guangzhou</td>
<td>1912</td>
<td>22.3</td>
<td>15 Apr</td>
<td>28 Oct</td>
</tr>
</tbody>
</table>

3. Results

Figure 1 shows the linear relationship between Ds and April mean temperature (Figs. 1a, c) and that between De and October mean temperature (Figs. 1b, d). The coefficients show a latitudinal gradient across the 16 stations. It is clear that a shift of Ds is determined not only by the change in April temperature but also by its sensitivity to temperature change. Similarly, in response to October warming (Fig. 4b), De experienced a delaying trend for most of the stations during the same period, with a rate up to 1.4 days per decade (Fig. 3b). Exception is for Tianjin, Nanjing, and Changsha, which show slight advancing trends of De. Consequently, the LGS exhibits a lengthening rate up to 3.3 days per decade (Fig. 3c).

We compute the regional mean LGS indices by using the data at all the 16 stations. The regional mean Ds (De) shows an advancing (delaying) rate of about −1.0 (0.5) days per decade for the period 1909−2012 (Figs. 5a, b). Consequently, the length of LGS has increased by a rate of about 1.5 days per decade (Fig. 5c).

However, the changes of the LGS indices are not monotonic but with multidecadal variability during the whole period. The Ds (De) time series exhibits enhanced advancing (delaying) trends during two periods, one from about 1910 to 1940, and another from about 1965 to 2012. Between them there is a slight delaying (advancing) period. The Ds (De) shows an advancing (delaying) rate of about −2.0 (1.5) days per decade for the period 1965−2012, leading to a lengthening of LGS with a rate of about 3.5 days per decade.
4. Conclusions

In this study, we investigate and quantify the long-term variations of thermal growing season in eastern China. The lengthening rate of LGS is about 1.5 days per decade for 1909–2012. The changes of the LGS indices have multidecadal variability for the whole period. Rapid changes in LGS occur in the last few decades, especially from 1965 onward (Fig. 5). For the period 1965–2012, the LGS has extended with a rate of 3.5 days per decade. This result for the last few decades is comparable with those of Qian et al (2012) based on homogenized temperature records from hundreds of stations in China. However, the present rate estimate is larger than the results of some previous studies (Xu and Ren 2004; Liu et al. 2010; Song et al. 2010; Yang et al. 2013). These differences are partly due to considerable multidecadal variability in LGS, which experienced a shortening trend before 1965 followed by an enhancing lengthening trend afterwards. The present study shows a historical perspective of changes in growing season in China.

Xia et al. (2013) found that multidecadal variability in LGS indices could be linked to the Atlantic Multidecadal Oscillation (AMO), which is expressed as the multidecadal variations of the North Atlantic sea surface temperature with a period of about 65–80 years and amplitude of 0.4°C (Schlesinger and Ramankutty 1994; Trenberth and Shea 2006). They suggested that the AMO-related multidecadal variability accelerates the lengthening of LGS in the Northern Hemisphere by about 53% for the last three decades. Following the way of Xia et al. (2013), we estimate that the contribution of multidecadal variability (extracted by using EEMD method) to the lengthening of LGS is about 35% (1.2 days per decade) in eastern China, for the period 1965–2012.

It is worth noting that eastern China experienced rapid development during the last few decades. Urbanization might exert some warming bias in the observed local temperature series. According to the recent analyses of Wang et al (2013) for Beijing and Zhao et al. (2014) for the 16 stations studied in the present paper, possible contribution from urbanization would be less than 10%
of the observed warming trend since the 1960s. Yang et al. (2013) also found that the urbanization effects contributed to about 10% of the growing degree days increase in eastern China during the last several decades. We suggested that one tenth of the lengthening of LGS for recent decades could have been a consequence of urbanization.

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References


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