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Evaluating the onset, end, and length of seasons in selected stations in Iran

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Abstract

Specifying seasons is one of the most significant and arduous parts of climatology studies. In the present study, seasons are defined to apparent temperature index. For determining changes in the length, start, and end dates of the season in Iran in line with global climate change, in this research we used daily data of apparent temperature for 32 synoptic stations with locations and topography over a 60-year period (1959–2018). Temperature indices used for determining the start of seasons are thresholds of apparent temperatures of 0 and 20 degrees, with a 10-day continuation and without reverting to the initial conditions during this period for winter and summer, respectively. In the same vein, transitional seasons were specified and changes were analyzed using linear regression. The findings revealed that, in various regions, the start of spring and summer occur earlier while the start of fall and winter are delayed. The biggest statistically significant changes are observed at the start of the spring and fall seasons, as the increase is 2.25 days for summer and 1.5 days for winter per decade. Therefore, the duration of cold seasons have decreased and the duration of warm seasons have increased in climatic regions. These changes are statistically significant in foothill and high-altitude regions; the hot and dry climatic range is expanding with the increase and decrease of the summer and winter length, respectively. However, considering the inhomogeneity of altitude and geographical phenomena in the Iranian plateau and its flat northern and southern regions, these changes are not uniform or equivalent. We can say that, overall, climate change, as a direct factor influencing season change and climatic belts, plays a more influential role in comparison with local factors.

1 Introduction

According to the reports of the Intergovernmental Panel on Climate Change, in the second half of the previous century, the global warming has been accompanied by an increase in the levels of CO_2 production caused by humans' consumption of fossil fuels, and this trend is expected to continue in the future. The most recent report of the Intergovernmental Panel on Climate Change denotes an increase of 0.99 (1.4–1.8) degree in earth's temperature compared to the period of 1850–1900 which, in an optimistic scenario by midcentury, will result in an increase of 1.5 to 2 degrees compared with the base period (Allan et al. 2021). The consequences of climate change include increased environmental hazards and climatic abnormalities which entail more occurrence of droughts on the globe (Dai 2011), east Africa (Haile et al. 2020), and northeast Spain (Gaitan et al. 2020); torrential rains and floods on the globe (Markus 2019; Tabari 2020); and heat waves on the globe (Marx et al. 2021), Germany (Zacharias et al. 2015), Africa (Engdaw et al. 2021), and north China (Kang et al. 2018). Some of the consequences of climate change that affect the earth's ecosystem are extinction in some parts of the world (Thomas et al. 2004), decrease in the population of plants and animals, and immigration in different parts of the world (Aitken et al. 2008; Carey 2009; Gomez-Ruiz and Lacher, 2019). The behavior of plants and animals is in line with the movement of the sun, changes in environmental temperature, and the start and end dates of thermal seasons. Therefore, global warming and man-made climate changes cause changes in the characteristics of seasons. Researchers have studied these changes using varied methods such as fixed thermal thresholds (Jaagus et al. 2003; Majewski et al. 2014; Kitowski et al. 2019; Ruosteenoja et al. 2020), classification of air masses (Lamb, 1950; Cheng et al.

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1997; Alpert et al. 2004), and phenological indices (Cayan et al. 2001; Wang et al. 2021). Considering that plants' and animals' phenological stages are linked with the climate, the signs of season changes become apparent in their lives (Penuelas and Filella 2001). Living creatures show different reactions to seasonal and temporal changes as well as to increases in the length of plants' growing seasons and adjust their phenological stages with them (Bradshaw and Holzapfel 2008). Immigrant birds' reaction to seasonal changes have altered; that is, early onset of spring, as an opportunity for birds to raise their chicks, has become a motivation for birds to migrate earlier and arrive at their destinations at earlier times; similarly, increased duration of summer and delayed onset of fall make them stay for longer periods (Lehikoinen et al. 2004). Considering the trend of global warming and changes in the seasons, the difference between winter and summer has decreased and the onset of seasons in coastal regions differs from the onset of seasons in continental areas (Thomson 2009). Changes in seasons can be seen in middle latitudes of Europe in early onset of spring in 1990s and the phenological effects (Palus et al. 2005). Temporal patterns and processes affect the lifecycle of plants and animals (Penuelas and Filella 2001). In recent decades, the onset of seasons and phenological processes in various species have changed, although the changes vary among different species (Thackeray et al. 2014). Researchers have studied changes in the onset and end dates of seasons and their duration; many studies show that there is a relationship between increased duration of the growing season and global warming; these conditions affect both plant and animal ecosystems (Linderholm 2006). Studies on season changes that are related with global warming are indicative of advancement of spring, delayed fall, and short winters, all of which are accompanied by an increase in the growing season's duration (Sparks and Mevzel 2002). Examples are studies on Estonia (Jaagus and Ahas, 2000), East European plains (Jaagus et al. 2003), China (Dong et al. 2010), Northwestern China (Jiang et al. 2011), and on Poland (Kitowski et al. 2019). Changes in the seasons' duration associated with global warming in the middle latitudes of the northern hemisphere revealed that, for the most part, summer becomes longer whereas winter becomes shorter. This happens because of delays in the onset and end dates of these seasons together with shortening of the duration of spring and fall. Such changes are linked with global warming and will intensify even if this warming trend does not accelerate. According to the base scenario, the summer will span nearly half the year and the winter will be confined to only 2 months. These changes endanger the order of life for living creatures and create hazards for human life (Wang et al. 2021). Spatial and temporal patterns of change in the onset of spring in north-western USA was investigated using the spring index (based on minimum and maximum temperatures) as well as the principal component analysis. The findings revealed two major, independent patterns. Overall, early onset of spring for as much as 1.5 days per decade and spatial changes of the seasons in the USA (Ault et al. 2011, Schwartz et al. 2013). Changes in the onset of spring for the period 1955–2003 were recorded using daily temperatures and an early onset of spring with 2.98 days per decade was recorded in Beijing. In northern China, spring started earlier; however, compared to western regions, in eastern areas this phenomenon occurred more and was more statistically significant (Qian et al. 2011). Changes in spring phenology in high and middle latitudes are associated with temperature fluctuations in winter; hence, with a warmer spring, the growing season starts earlier. This is a significant environmental factor concerning phenology and ecosystems (D'Odorico et al. 2002). Changes in thermal cycles are a response to global climate change, for example, in China (Song et al. 2010), Eastern Europe (Schmidt et al. 2012), and Africa (Cook and Vizy 2012). Regarding the climate change, changes in the onset and end dates and the length of seasons have been investigated using different indicators. Examples are the start of plants' blooming in England by Kirbyshire and Bigg (2010), temperature thresholds in Europe by Pena-Ortiz (2015), apparent temperature in the USA by Allen and Sheridan (2016), and fixed temperature threshold in Poland by Czernecki and Mietus (2017). Concerning climate change and global warming, Indian monsoon systems mainly changed after 1970. The monsoon currents followed a path toward west. In addition to the effects of monsoon systems on the level and intensity of rainfalls, a 15-day increase and delay in the start of monsoon rainfalls was predicted (Loo et al. 2015). The warming of the northern hemisphere and warm winters are linked to the positive trend of Arctic Oscillation and winter respiration. They are in line with increased photosynthesis in spring and are indicative of increased seasonal amplitudes in observed atmospheric CO_2 concentration (Schaefer et al. 2005). From the distant past, Iran's climate has experienced dry and humid periods and it has a so-called climatic instability and periodically fluctuating climate (Emadodin et al. 2019). Considering scattered mountains in Iran, this spatial-climatic trend varies on a local scale. Global warming models predict increased anomalies accompanied by intense periods of drought preceding periods of torrential rain and flood in Iran (Afshar Vaghefi et al. 2019). Iran has become warmer in recent decades to the extent that from 1951 to 2013 its temperature has increased by 1.3 degrees (0.2 degrees per decade). Iran's rainfall has decreased by 8 mm per decade and its dry regions have expanded. Contrary to some studies which predict warmer weather is accompanied by increased moisture retention and precipitation, in

Iran, warmer temperatures have led to droughts and light precipitation (Alizadeh Choobari 2018). Models predict that as the levels of CO_2 will double by 2100, Iran's temperature will increase from 1.5 to 4.5 degrees which will have significant climatic and environmental consequences (Amiri et al. 2010). From 1970 onward, increased urban population, depletion of villages, and occurrences of many droughts in various parts of Iran have led to a fourfold increase in utilization of underground sources of water. This in itself has caused that levels of underground water table have decreased by 0.51 m per year. Droughts of recent years have also intensified desertification (Emadodin et al. 2019). In different climates, living conditions in ecosystems are set based on the repetition of weather conditions, and part of this repetition is determined by the onset and end of seasons. Changes in the onset and end of the seasons may cause major abnormal changes in human activities, planning, vegetation, gardens, and animals' behaviors. Some human activities are directly related to the onset, end, and duration of seasons. In Iran, for example, the changes influence the cultivation and harvest of agricultural products, migration of nomads, tourism, traveling, energy consumption management, and management of wildlife. A huge part of works in Iran, especially in rural areas, depends on agriculture and animal husbandry, which is directly affected by the onset and end of seasons. Therefore, earlier or later onset of seasons affect planting and harvesting. Such effects can be abnormalities in the sprouting time of trees, frost, and extreme heat. Changes in the onset and length of seasons influence the life of wild species of Iran and all other species that their lives depend on the regularity of seasons. Increase in temperature and climate changes may have such effects in Iran as increase in climate hazards, frequent hazardous weather events, health challenges caused by air pollution, increase of diseases transmitted by water, food and vectors, decrease of well-being of society, and deaths caused by weather events (Mousavi et al. 2020). Therefore, recognizing the changes associated with global warming will help planners in Iran. Determining season changes through recognizing climate changes on regional scale in arid, semi-arid, cold, steppe, and temperate climates of Iran will be of great importance. The study aims to identify the characteristics (i.e., onset and end) and changes of seasons in Iran through constant temperature indices. One of the most important consequences of global warming is revealed on a regional scale in this research. Considering the climatic diversity in Iran, it is important to know the characteristics and changes of seasons in the 60-year period (1959–2018), keeping in mind global warming and changes in average temperatures. This research will be useful for Iran's environment policymakers and climate researchers in the future with the aim of reducing the consequences of these changes.

2 Climate of Iran

Iran is located in the Middle East between 25 and 40° north and 45 and 65° east. This country is adjacent to the open waters of the Oman Sea and the Persian Gulf in the south, the Iraqi Plain in the west, and the Caspian Sea and the low-lying lands of Turkmenistan in the north (Fig. 1). The climate of Iran during a year can be divided into cold-wet and hot-dry periods. In the cold period of the year, cold and dry air mass enter from northeast Iran and cold and humid air from the northwest and west. During the warm period of the year, the warm and dry air mass of Saudi Arabia and subtropical regions enter from the southwest and south of Iran. The onset of the warm season in the south and southwest is earlier than other regions and the season begins with a delay in the north and northwest of Iran. In general, major parts of the south, east, and center of Iran have desert climates, southern regions are warm and dry, and the northern parts are cold and dry. Next to this climatic region, in mountain slopes, there are cold and hot semi-arid climates. The diversity of Iran's climatic regions depends on local and external factors. The most important external factors affecting the climate of Iran in the general circulation of the atmosphere are western winds and Siberian high pressure in the cold period of the year, subtropical high pressure in the warm period of the year, low pressure of Iran, monsoon of Southeast Asia, and 120-day winds in the eastern Iran. Mountains are the most important factor in Iran's climate diversity.

3 Data and research method

To investigate the seasons in this study, we used the data for daily relative humidity (*Rh*, %), vapor pressure (P_v, hpa), wind speed (V_{10}, m s^{-1}), and daily temperatures (T_a, °C) in 32 synoptic stations of Iran over the 60-year period from 1959 to 2018 (Fig. 1). Data for each location were obtained from I.R. of Iran Meteorological Organization (IRIMO). Considering Iran's geographical location and diversity of geographical phenomena, its synoptic stations were chosen in a way that cover all the regions of Iran. As a result, they cover an area ranging from coastal area of the Caspian Sea with an altitude lower than that of open seas, to the low-altitude coasts of the Persian Gulf and the Gulf of Oman in the south, and to the mountainous areas of western and northwestern Iran and its central foothill and low-altitude areas.

In this study, to determine the start and end dates of seasons, the daily apparent temperature was used (Eq. 1; Steadman 1994). Apparent temperature was chosen to represent seasons since the metric represents a broad range of climatological indicators (Allen and Sheridan, 2016). Daily apparent temperature is a mixed index of daily parameters of wind, relative humidity, and air temperature. In this study, the basis

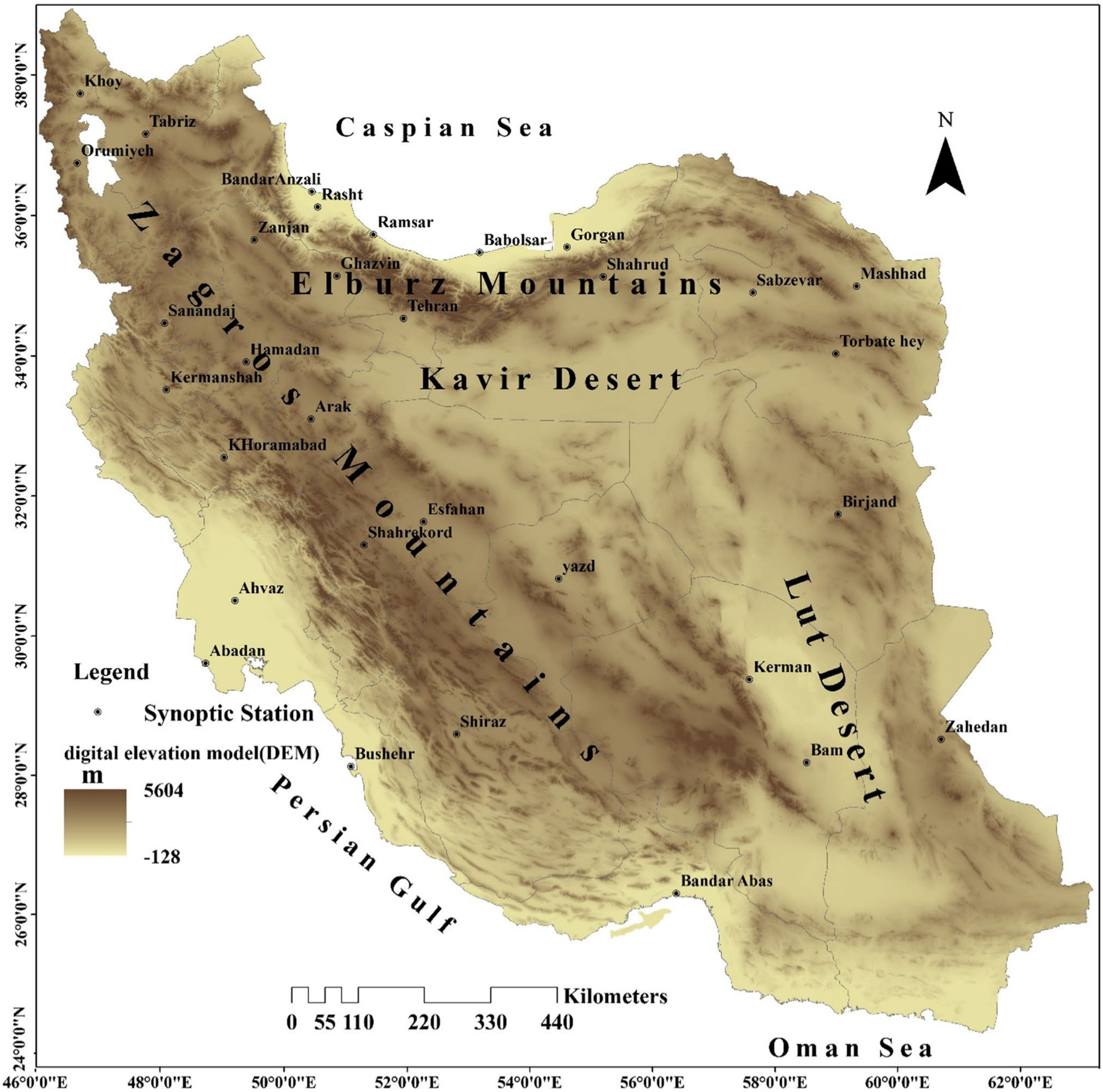

Fig. 1 Location of selected synoptic meteorological stations from Iran

of determining the characteristics of seasons is temperature indices. In order to explain and confirm the selection of temperature indicators, the facts of the physiological behavior of organisms in accordance with the temperature were used. The best temperature for the growth period in nature is zero as the minimum and 30 as the maximum; therefore, at temperatures below zero, growing stops (Abrami 1972). The second key indicator is the temperature at the onset of summer and the warm period. For the onset of the summer, the base temperature was 20, which is the minimum temperature for the reproduction period in the majority of plants and animals. Plants like wheat which is the oldest grain in the world begin to form seeds at this temperature (Jenner 1991; Dupont and Altenbach 2003). Daily apparent temperature of 0 and 20 degrees were used as two important temperature indicators to determine the winter and summer and transitional seasons, which are roughly proportional to the physiological behavior of plants and animals and related to the activities and aspects of human comfort. Moreover, in this study, the daily sequence and continuity of a specific temperature during at least 10 days in each index was the basis for the onset of the seasons because the minimum time required for adapting to new temperature conditions is 10 days (Joy 2017).

$$AT = T_a + 0.33\ P_V - 0.7\mathrm{v}_{10} - 4 \quad (1)$$

Here, AT = apparent temperature, T_a = air temperature, P_V = vapor pressure, and v_{10} = wind speed.

4 Definition of season

Factors of atmospheric flow paly a direct role in the occurrence of natural phenomenon including new thermal conditions (seasons) in middle latitudes. Knowing this issue and based on the longevity of the migratory systems (cyclones and anticyclones) in middle latitudes (Alijani 1995), we calculated the 4-day moving averages of the apparent temperature data for each station. Using the daily data and based on a specific temperature index in the definition of the onset of each season, the onset and end of each season are determined as follows: the onset and end of winter with a temperature below zero, the onset and end of spring with a temperature above zero and below 20, the onset and end of summer with a temperature above 20, and the onset and end of fall with a temperature less than 20 and more than zero. Based on these temperature indices, the onset and end times of the seasons were determined in each year at each station (Fig. 2a, b); that is, 1 to 365 days in common years and 366 days in leap years. This was done for each individual year up to 60 years for all stations. Based on the onset and end time during the 60 years, the average onset and end of the seasons was calculated for the entire period. Moreover, the onset and end date of season in each station were determined. The length of season was calculated based on the interval between the onset and end of each season in each year separately, and its average for the 60 years is the season length of each station (Table 1).

Winter thermal indices → Onset = AT ≤ 0°C, End = AT > 0°C, Length = day number of onset − day number of end

Spring thermal indices → Onset = AT > 0°C, End = AT < 20°C, Length = day number of onset − day number of end

Summer thermal indices → Onset = AT ≥ 20°C, End = AT < 20°C, Length = day number of onset − day number of end

Fall thermal indices → Onset = AT < 20°C, End = AT > 0°C, Length = day number of onset − day number of end

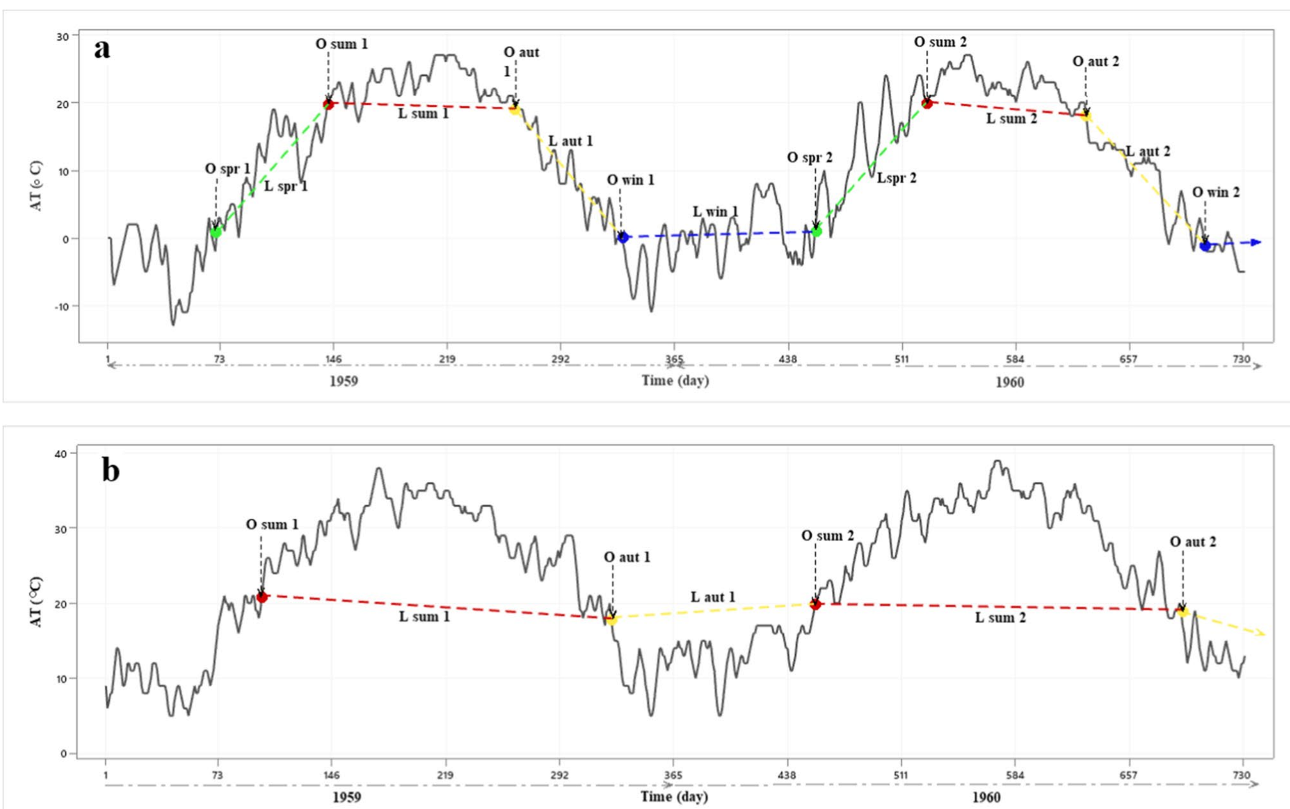

Fig. 2 Thermal indices of time series of daily apparent temperature (AT). **a** Onset of spring (O spr), onset of summer (O sum), onset of autumn (O aut), onset of winter (O win), length of spring (L spr), length of summer (L sum), length of autumn (L aut), and length of winter (L win). **b** Onset of summer (O sum), onset of autumn (O aut), length of summer (L sum), and length of autumn (L aut). The day before the onset of the new season is the end of the previous season

Table 1 Mean of seasonal start dates and durations in Iran (1959–2018)

Station	Elevation(m)	Mean spring	Mean length	Mean summer	Mean length	Mean fall	Mean length	Mean winter	Mean length
Abadan	7	–	–	6 Apr	225	17 Nov	140	–	–
Ahvaz	22.5	–	–	3 Apr	230	18 Nov	135	–	–
Arak	1703	28 Feb	101	9 Jun	102	20 Sep	91	20 Dec	71
Babolsar	−21	–	–	18 May	162	26 Oct	203	–	–
Bam	1067	–	–	17 Apr	194	27 Oct	171	–	–
Bandar Abas	10	–	–	3 Mar	290	19 Dec	75	–	–
Bandar Anza	−24	–	–	23 May	153	23 Oct	212	–	–
Birjand	1491	10 Feb	104	26 May	115	18 Sep	105	29 Dec	41
Bushehr	9	–	–	5 Apr	238	29 Nov	127	–	–
Esfahan	1552	16 Feb	102	27 May	125	29 Sep	93	27 Dec	45
Gorgan	0	–	–	13 May	165	24 Oct	200	–	–
Hamadan	1680	21 Mar	102	1 Jul	64	3 Sep	87	29 Nov	112
Kerman	1754	11 Feb	106	29 May	110	17 Sep	101	29 Dec	38
Kermanshah	1319	25 Feb	111	16 Jun	97	20 Sep	96	25 Dec	61
Khoramabad	1148	12 Feb	105	28 May	130	4 Oct	98	7 Jan	32
Khoy	1103	4 Mar	102	14 Jun	101	22 Sep	82	12 Dec	80
Mashhad	999	27 Feb	94	1 Jun	104	13 Sep	100	22 Dec	67
Oromia	1328	12 Mar	108	28 Jun	72	8 Sep	91	8 Dec	94
Qazvin	1279	27 Feb	101	9 Jun	107	24 Sep	89	21 Dec	68
Ramsar	−20	–	–	23 May	155	23 Oct	210	–	–
Rasht	−9	–	–	19 May	154	20 Oct	211	–	–
Sabzevar	962	18 Feb	91	20 May	135	2 Oct	89	28 Dec	50
Sanandaj	1373	1 Mar	104	13 Jun	98	20 Sep	90	19 Dec	73
Shahrood	1325	24 Feb	102	6 Jun	109	22 Sep	90	20 Dec	64
Shahrekord	2049	10 Mar	106	23 Jun	77	8 Sep	99	14 Dec	83
Shiraz	1488	–	–	21 May	138	5 Oct	227	–	–
Tabriz	1361	14 Mar	108	1 Jul	77	15 Sep	83	7 Dec	98
Tehran	1191	20 Feb	97	27 May	132	6 Oct	83	28 Dec	53
Torbat-Heydariah	1451	27 Feb	95	2 Jun	106	16 Sep	99	24 Dec	65
Yazd	1230	6 Feb	95	12 May	149	7 Oct	87	31 Dec	34
Zahedan	1370	31 Jan	101	12 May	134	25 Sep	101	28 Dec	29
Zanjan	1659	18 Mar	102	25 Jun	74	10 Sep	86	5 Dec	103

The vacancies in the table (–) for spring and winter in some stations indicate no winter and spring according to the definition of seasons in this study

The basis for the onset of winter is the temperature of zero without reverting to above-zero temperatures for 10 days and daily temperature decreasing trend. The continuation of subzero temperature in a region for 10 days conveys to living creatures in nature that a change has occurred and winter has started; after that, even if temperature exceeds zero for periods shorter than 10 days, things will not return to their previous states. This means that nature will not react. If in a station, the temperature does not reach zero or below zero, then according to this index, winter has not occurred (Fig. 2). Spring starts with the start of above-zero temperature (i.e., 1 degree and more) without returning back to 1 degree for the next 10 days; that is, temperature increases to more than 1 degree for a 10-day period or more (transfer from cold to heat). Rising temperatures in late winters and early springs are accompanied by the plants' blooming and birds' reproduction, nesting, and egg laying. If winter does not happen in a station, spring will not happen either, and it has two seasons; that is, fall and summer (Fig. 2). The starting temperature of summer and the warm period is a temperature of 20 degrees in line with previously mentioned conditions. Here, too, a 10-day continuation period without reverting to 20 degrees (daily temperature increase trend) is the basis for determining the season. For winter, if in a 10-day period the temperature returns to 20 degrees, it is not the onset of the season unless the previously mentioned conditions are met. In case these conditions are not met in a year in a station, at that year the summer has not occurred in that particular station (Fig. 2). The decreasing trend of temperature at the end of summer when temperature is less than 20 degrees, that is, 19 degrees and the decreasing trend continues for a 10-day period without returning back to 19 for the following 10 days, is a sign that fall has started (transfer from cold to heat). In some stations where winter does not happen, fall is connected to summer, that is, two-season station (Fig. 2). Changes in the onset and duration of seasons are calculated based on the onset date of seasons in each year for each station. Similarly, the duration of each season is calculated based on the onset and end dates of each season. In this paper, the amount of change and its statistical significance in each station were estimated using linear regression at a 0.05 level of significance. Moreover, average onset date and duration of seasons as well as changes in the starting date and the duration for each station were calculated. The amount of changes per decade are depicted on the maps. For all seasons, January 1 and December 31 were determined as the onset and end dates of the year, and 365 days for regular years and 366 days for leap years were determined. Moreover, by using spatial averages, the onset, end, duration, and changes of the seasons were determined in the climatic regions of Iran (Alijani 1995), including low coastal desert, central arid, semi-arid mountain foothills, cold mountainous areas, Mediterranean west of Zagros, and moderate coastal Caspian Sea.

5 Findings

There is no regularity in the four seasons in various regions of Iran. Considering that temperatures seldom reach zero or subzero levels in coastal regions of northern and southern Iran, these regions have two seasons of fall (cold) and summer (warm) and do not have winter or spring. Other regions of Iran, however, have four seasons with varying temporal and spatial distributions.

5.1 Spring

There is no spring in coastal regions of northern and southern Iran. Of the 32 stations in Iran, 11 stations did not have spring. Apart from these regions, Bam station located at the south of Lut Desert and Shiraz station at the south of Zagros Mountains, which are below the latitude of 29 degrees, had similar conditions. On average, February 25 was the onset of spring in other areas (Table 2). The earliest onset was January 31 in southeastern Iran, that is, Zahedan and the eastern fringe of Lut Desert. The latest onset of spring was March 21 in the high-altitude region of Zagros Mountains (Hamedan), located at the west of Iran (Table 1). During the six previous decades, the onset of spring has, on average, occurred 1.66 days earlier per decade (Table 2). Of 21 stations which had normal springs, early onset of spring occurred in 19 stations and no changes were observed in three stations at the center and southeast of Iran. The most significant change that is an early onset (3 days per decade) was observed in foothill regions of southeastern Iran (i.e., Mashhad) and also in Sanandaj (located at high-altitude western regions). Moreover, Tehran station as the most popular city and the capital of Iran, and Qazvin station at the southern foothill of Alborz Mountains and Khoramabad, located at western part of Zagros, had statistically significant changes (Fig. 2). On average, spring has a length of 102 days in Iran (Table 2). The longest is in Kermanshah with 111 days and the shortest is in Sabzevar, located to the east of Lut Desert, with 91 days. The duration of spring, on average, had increased 0.89 day per decade (Table 2). In most stations, an increase has been recorded. Of the 21 stations, shorter durations of spring were observed in five stations and the most significant change was recorded in Zahedan station with a decrease of more than 3 days per decade at the east of Lut Desert in southeastern Iran. Moreover, the duration of spring had increased in 16 stations. So, the biggest changes were recorded in high-altitude stations of Iran, that is, in Torbat Heydarieh and Zanjan Stations, located at northeastern and northwestern regions of Iran, respectively. The length of spring had increased by more than 3 days per decade in these stations. Moreover, Urimia, which is located at the northwestern part of Iran and the west of Lake Urimia, experienced a statistically significant increase in the duration of spring (Fig. 3). The biggest positive and statistically significant increase in the duration of spring happened in northern and northwestern parts of Iran. The biggest negative change, that is, the shortening of spring's duration, was in Zahedan. In other regions of Iran, changes were less than 1 day and were not statistically significant.

Table 2 Mean changes (days decade^{-1}) to seasons of Iran (1959–2018)

Season	Spring		Summer		Fall		Winter	
Parameter	Start	Length	Start	Length	Start	Length	Start	Length
4-season	25 Feb	102	7 June	106	20 Sep	92	21 Dec	65
2-season	–	–	27 May	191	4 Nov	174	–	–
Change	−1.66	0.89	−0.76	2.25	1.13	−.094	0.1	−1.5

A negative trend indicates early onset of the season (reduced duration) and a positive trend indicates delayed onset (increased duration)

5.2 Winter

Considering the lack of freezing, subzero temperatures, northern and southern coastal regions of Iran do not have a real winter but in the coastal areas of the Caspian Sea, sometimes, haphazardly and for several days, the temperature reaches zero or subzero. In other regions of Iran, on average, winter starts on December 21 (Table 2). The earliest onset of winter happened in Hamedan on November 29 and the latest onset of winter happened on January 7 in

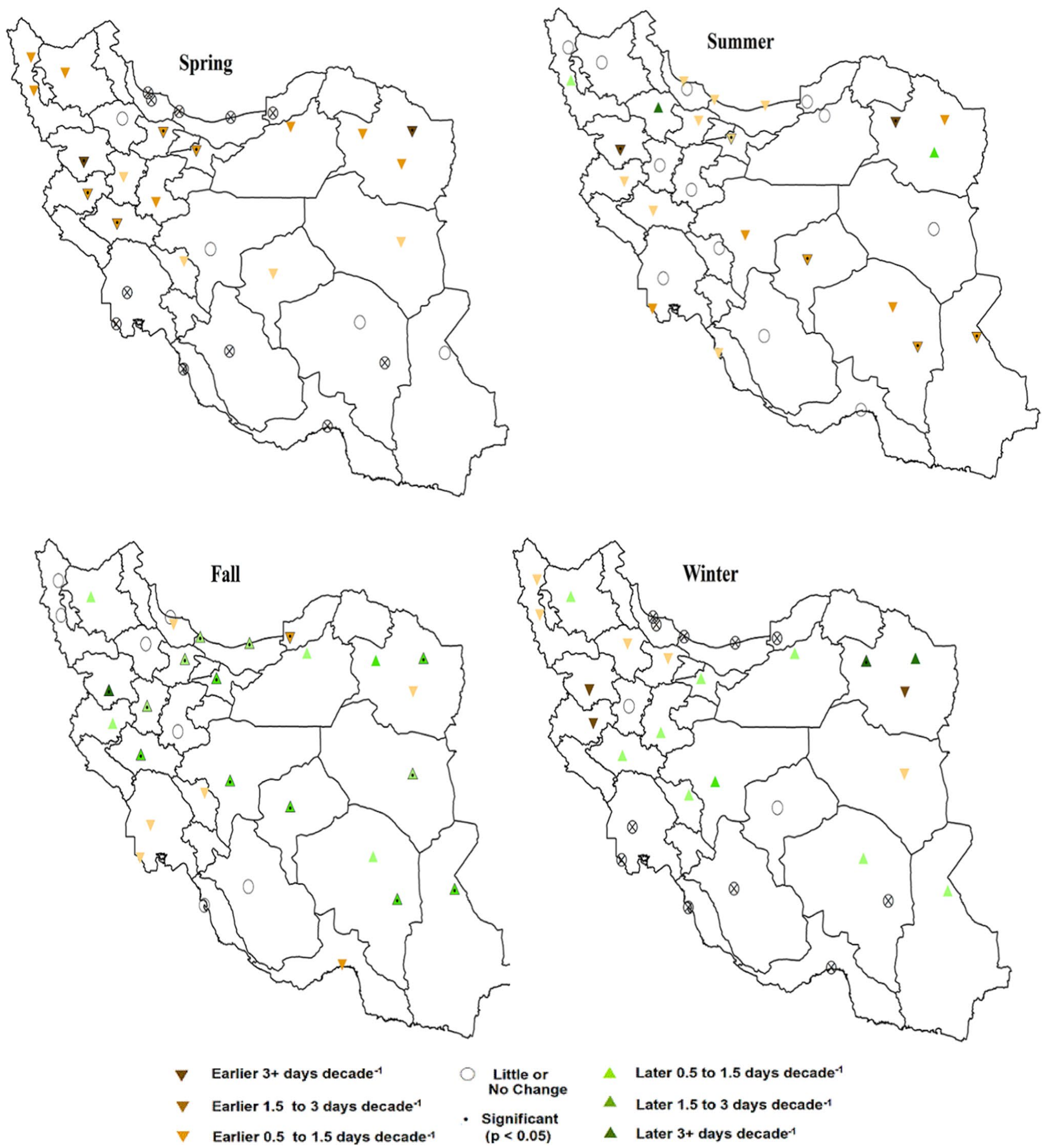

Fig. 3 Mean changes for seasonal start dates of Iran (1959–2018). Downward arrow indicates an earlier start date while upward arrow indicates a later start date. Significant values are represented by a dot

Khoramabad, located at the southwest of Zagros (Table 1). Over the past six decades, the onset of winter in Iran was, on average, delayed by 0.1 day per decade (Table 2). As a result, of 21 stations of Iran, in 6 stations early onset of winter, in 9 stations delayed onset of winter, and in 6 statins no changes or small and insignificant changes in the onset of winter were observed. With more than 3 days per decade, the earliest onset of winter was recorded in high-altitude stations of Torbat Heydarieh, located at eastern Iran, as well as in Sanandaj and Kermanshah stations, located at western Iran. In terms of delay in the onset of winter, the biggest changes with more than 3 days per decade were observed in foothill stations of northeastern Iran (i.e., Mashhad and Sabzevar) and in Isfahan that is located at the foothill region of eastern Zagros, which had an average of 2 days per decade. These changes were statistically significant only in Sabzevar station. On average, winter has a length of 65 days in Iran (Table 2). The longest duration of winter was in high-altitude regions of west and northwest (i.e., Hamedan with 112 days) and the shortest was in Zahedan, located at the south of Iran, with 29 days. The duration of winter, on average, had decreased by 1.5 days per decade in Iran (Table 2). Three stations had an increasing, although statistically insignificant, trend. Five stations did not record any changes and 13 stations had a decreasing trend in the duration of winter. The biggest decrease in the duration of winter were recorded in Mashhad, Zanjan, and Shahrood, with a decrease of more than 3 days per decade. Changes in Tehran, Khorramabad, and Shahrood stations were statistically significant; hence, in most regions of Iran (i.e., from northwest to northeast), the duration of winter has decreased. The biggest changes in terms of the early onset of winter were in Mashhad, Zahedan, and Kermanshah and the smallest changes in the early onset of winter were in the coastal region of the Caspian Sea. The biggest statistically significant changes in winter were in western, northwestern, and northeastern areas of Iran.

5.3 Summer

During the period of 1959–2018, in four-season regions, the summer on average started on June 7 and in two-season regions it started on May 27 (Table 2). The earliest onset of summer was in coastal regions of south on March 3 (i.e., in Bandar Abbas which is located on the fringes of Persian Gulf). The latest onset of summer was in high-altitude western and northwestern regions of Iran (i.e., Hamedan and Tabriz) on July 1 (Table 1). On average, the onset of summer in Iran happens 0.76 day earlier per decade (Table 2). Of 32 stations, 26 stations had a negative trend and experienced early onset of summer, 3 stations had delayed and statistically insignificant starts while there was no change in the start of summer in 3 other stations during the past six decades. All over Iran, the biggest changes in the onset of summer with a change of more than 3 days per decade belonged to Sabzevar and Sanandaj stations, located on northeast and northwest of Iran, respectively. Moreover, changes in Zahedan, Yazd, Tehran, Bam, and Babolsar, located on northern coasts of Iran, were statistically significant. On average, the duration of summer in Iran is 106 and 191 days for four-season and two-season regions, respectively (Table 2). Hamedan, located on the east of Iran, with 64 days and Bandarabas, located on the southern coast of Iran, with 290 days had the shortest and the longest summers, respectively (Table 1). In addition, the duration of summer had, on average, increased by 2.25 days per decade (Table 2). Of the four seasons of Iran, the duration of summer had increased more than other seasons; therefore, 25 stations had an increasing trend in the duration of summer and 3 stations had a negative but statistically insignificant trend. In Torbat Heydariyeh, located on the high-altitude region of eastern Iran, an increasing trend for the duration of summer was observed and four stations recorded little change or no changes at all. With more than 3 days per decade, the biggest changes were in foothill and plateau stations of Zahedan, Yazd, Isfahan, Bam, Tehran, Mashhad, Sabzevar, and Sanandaj (Fig. 3); hence, in most regions of Iran, the duration of summer has increased. Moreover, in the coastal regions of the Caspian Sea, the duration of summer has increased over the past six decades; however, in some mostly mountainous regions, the duration of summer had decreased and this decrease was statistically significant.

5.4 Fall

The start of summer in four-season regions of Iran is on average September 20, while in two-season regions fall starts on November 2 (Table 2). The onset of fall, on average, has been delayed by 1.13 days per decade (Table 2); hence, of 32 stations, 10 stations experienced early start of fall or no statistically significant changes while 22 stations had delayed starts of fall. The biggest change was in Sanandaj station, located on western Iran, with an early start of 3 days per decade. In most foothill stations including Tehran, Zahedan, Sabzevar, Mashhad, and Isfahan, this trend was statistically significant (Table 1). Of the seasons in Iran, the biggest statistically significant change in this season concerned delayed starts. On average, the duration of fall in four-season and two-season regions was 92 and 174 days (Table 2), respectively. Shiraz with 227 days had the longest fall and Bandar Abbas with 75 days had the shortest fall. The duration of fall had a 0.09-day decrease per decade (Table 2); accordingly, on average, fall has become 0.09 day shorter per decade in Iran and it has a delayed start. The biggest changes were in Zanjan, Sanandaj, and Bam, with a decrease of 3 days per decade. Moreover, in Zahedan and Yazd stations, located on the fringes of Lut Desert, as well as in Ramsar and Babolsar stations, located on the coastal areas of the Caspian Sea, there was a statistically significant increase in the shortening of fall's duration. Of 32 stations, in 18 stations, the duration of fall has decreased, 8 stations recorded no changes, and in 6 stations, mostly located on high-altitude regions of Alborz, there was an increase in the duration of this season which was not statistically significant. In most regions, the onset of fall is delayed, but in some regions, including mountainous regions, the onset of fall happens earlier. Moreover, in coastal regions of the Caspian Sea, the onset of fall is delayed.

6 Discussion

In this research, changes in the onset of the seasons were analyzed using apparent-temperature data for 60 years (1955–2018), the longest time span for which the meteorological data of the synoptic stations of Iran are available. The basis of determining a season is the constant temperature index in line with the physiological behavior of the organisms. That is, human beings, animals, and plants adapt their stages of life (phenology) to season changes and, in the long run, environmental compatibility and adaptability are created. It is obvious that in line with global warming and the increasing trend of earth's temperature in recent decades (Allan et al. 2021), as well as the temperature abnormalities, seasons have become abnormal, creatures' phenology has changed, and disruptions have been made in their lives (Aitken et al. 2008; Carey 2009; Gomez-Ruiz et al. 2019). These conditions are more deleterious to unstable climate of Iran which is located between subtropical and temperate regions of the earth. Low-altitude regions of the Iranian Plateau located on the coastal regions of Gulf of Oman, Persian Gulf, and the Khuzestan Plain as well as the beaches of the Caspian Sea have two seasons. With the exception of Bam station, located in the south of Lut Desert, and Shiraz, located in the south of Zagros and in the vicinity of Persian Gulf, other regions of the Iranian Plateau have four seasons. This indicates the role of altitude and geographical phenomena in the diversity of seasons. Considering the role of these phenomena, we can see that seasons in Iran are not homogeneous. The southern regions of Iran due to their proximity to subtropical regions have seasons which are more similar to those of the desert climate and have two seasons: a long summer and a short cold season. Moreover, coastal regions of the Caspian Sea, located in the northern foothill of Alborz, due to the influence of the sea, have a temperate, two-season climate. Contrary to the southern coastal regions, northern coasts of Iran have longer cool seasons and shorter summers. This shows that latitude plays a minor role in the diversity of seasons but a significant role in the duration of seasons. Other regions located between the two areas of the Iranian Plateau have four seasons. As we move from the northwest to southeast, the duration of the hot and dry season (summer) increases and the duration of the cold season decreases. So, the northwest of Iran has longer cold seasons while in its southeaster regions which are close to subtropical climate, the duration of hot season increases. That is, by moving from the northwest of Iran to its southeast, seasons become less moderate and the desert aspect of the climate becomes more salient. This change is usually less in transitional seasons, but it is more in winter and summer. That is, summers are longer in southeastern regions and winters are shorter. As we move toward northwest and high-altitude regions of Iran, winters become longer. The 90-day duration of seasons fluctuates as we move from northwest and west toward the east and southeast. Spatially, the biggest statistically significant changes in the start of spring concern early starts, which can be associated with increased thermal waves at the end of winter due to global warming (Mansoori Daneshvar et al. 2019). The early start of spring creates many disruptions in the phenological life of plants and animals. In foothill regions where most of the Iranian cities are located as well as in the fringes of Lut Desert at southeast of Iran, the early start of summer is statistically significant. On the other hand, the start of winter is delayed in foothill and central regions of Iran, which indicates that these regions are influenced by global warming and that cold air masses have not reached these regions. The start of fall in most regions of Iran is delayed and this delay is statistically significant. Of all the seasons, the biggest statistically significant change is observed in the start of fall; therefore, as far as global warming and climate change are concerned, warm seasons in Iran have started earlier and the start of cold seasons have been delayed. During the studied period (1959–2018), some changes occurred in the duration of seasons. The start and duration of cold seasons are similar and the start and duration of warm seasons are also alike. In most regions of Iran, the start of the cold seasons is delayed and they have become shorter; however, warm seasons start earlier and their duration has increased. Moreover, most spatially homogenous changes occur in transitional seasons, such that in all regions of Iran, springs start earlier and falls, which have the most spatially homogeneity among temperate regions of Iran, have a delayed start. In the same vein, the duration of seasons in various regions of Iran has also had some changes; so, the duration of springs and summers has increased and the duration of falls and winters has decreased. Summer has the biggest statistically significant changes. Changes in the start of summer differ in various parts of Iran. In most regions, summer starts earlier and this early onset is statistically significant, but the start of summer is delayed in some mountainous regions. The biggest fluctuations in the duration of seasons occur in the summer, such that in most regions of Iran, the duration of summer has had a statistically significant increase (Fig. 4). These changes in the duration of seasons cause disruptions in the life of creatures. The biggest fluctuations in terms of changes in the duration of seasons occur in summer, and this is indicative of the influence of geographical phenomena and geographical location, particularly altitude, on the amount of absorbed radiation and on the onset and variability of this season. Therefore, this season in most regions of Iran is shaped by amounts of absorbed radiation and kernels of local pressure on local to moderate scales. The widest diversity in terms of wind patterns is observed in this season which affects the apparent temperature and changes of seasons. The shortening of the duration of summer in eastern parts of Iran can be potentially linked to the cooling effect of 120-day winds of Sistan and Baluchestan province and the reduced apparent temperature. Among the seasons of Iran, there was a moderate but statistically significant link between changes in the start of fall and altitude which shows that as altitude increases, changes occur in the onset of fall. In other words, in higher altitudes, the start of fall is delayed. This is linked to climate changes and their effects on these geographical areas. However, no statistically significant link was observed between altitude and changes in the duration of other seasons. Changes in the duration of fall, as a transitional season, in various regions of Iran is indicative of the smallest change among four seasons or between the summer and fall. That is, on average, there is less than 3 days of positive or negative fluctuation in this season. Nearly half of Iranian regions experienced positive changes or an increase in the duration of fall and the other half experienced a negative change or a decrease in the duration of fall (Fig. 4). The role of latitude and altitude on one hand and the factors of atmospheric circulation and climatic season, on the other hand, are quite apparent in this change. Shorter duration of fall in two-season coastal regions of southern and northern Iran is caused by the arrival of less cold air masses and is nearly synonymous with reduced duration of winter in other four-season regions. The onset of winter is delayed. On the other hand, in some regions, changes in the early start of winter are not statistically significant. These changes denote the diversity of seasonal conditions in various parts of Iran. For the most part, the onset of winter occurs in northwestern regions which are a point of entry for migratory anticyclones and the onset of fall occurs with the entrance of the Siberian High from the northeast and east. However, season changes are indicative of changes in the behavior of these climatic patterns. Changes in the duration of spring differ in various parts of Iran. In most regions, the duration of spring either increased or remained unchanged while in other regions the duration of this season decreased (Fig. 4).

Moreover, in this study, the characteristics of seasons and their changes during the last six decades were investigated in the climatic regions of Iran (six regions). The characteristics of the seasons in the climatic regions from the south to north of Iran are as follows: the temperature does not reach zero or less during the year in areas with a coastal desert climate in the south of Iran and a temperate climate on the shores of the Caspian Sea, respectively, due to the stability of the air in subtropical latitudes and low altitude and the effect of the waters of the Caspian Sea in the north. Moreover, winter does not happen according to the definition of seasons in this study. Therefore, these areas have two seasons: fall and summer. This is similar to some regions of China (Ma et al. 2020). In both regions, summer and fall start earlier and the duration of summer and fall increases and decreases, respectively (Table 3), as the length of fall in Ahwaz in the south of Iran increases (Hekmatzadeh et al. 2020). In the four other climatic regions of Iran (central arid, semi-arid foothills, cold mountainous, and Mediterranean in the west of Zagros), during the last six decades, spring and summer have started earlier and fall and winter started later. This is similar to what happens in other parts of the globe, including Estonia (Jaagus and Ahas 2000), Poland (Kitowski et al. 2019), the USA (Schwartz et al. 2013), earlier onset of spring in China (Qian et al. 2011; Song et al. 2010), and earlier onset of spring and later onset of fall in northwest China (Jiang et al. 2011). The length of spring in two mountainous and dry regions is significant with an increase and decrease of 2 days per decade. This shows longer summers and springs and shorter falls and winters. Moreover, the length of summer in the central arid and semi-arid mountainous regions increases by 4 days per decade, and in the Mediterranean climate region of the west of Zagros and the cold mountainous climate, it increases by 2 and 1 days per decade, respectively (Table 3; Fig. 5). Winter is the shortest season in the climatic regions of Iran, but among the regions, the longest winter is in the cold mountainous climatic region due to the high altitude and local conditions. Toward the central arid regions, the length of the season decreases to less than 1 month in a year (Fig. 5). This is similar to some areas of Eastern Europe (Jaagus et al. 2003) and some areas in China (Dong et al, 2010). This could be due to Iran's geographic location in the subtropical region on the desert belt of the world, the less arrival and non-arrival of cold weather in different regions of Iran, and the effects of global warming on a large scale in the past few decades (Sparks and Mevzel 2002). The length of seasons is more regular in the cold mountainous climatic regions, but winter in the Mediterranean and cold mountain climates decrease 2.79 and 1.71 days per decade, respectively (Table 3). Moreover, the length of the fall decreases in all regions and it is significant in the dry climate as it decreases 2 days per decade. This can be due to the distance from the cold and wet masses, the low altitude of the regions, and proximity to the subtropical belt on the one hand, and on the other hand, due to the global warming, the expansion of the subtropical regions, and weakening trend of fall weather patterns, including Siberia and high pressures coming from northwest Iran.

7 Conclusion

The studied period in this research (1959–2018) is the time when a rapid increase in global temperature happens in the world. One of the consequences of global warming is the

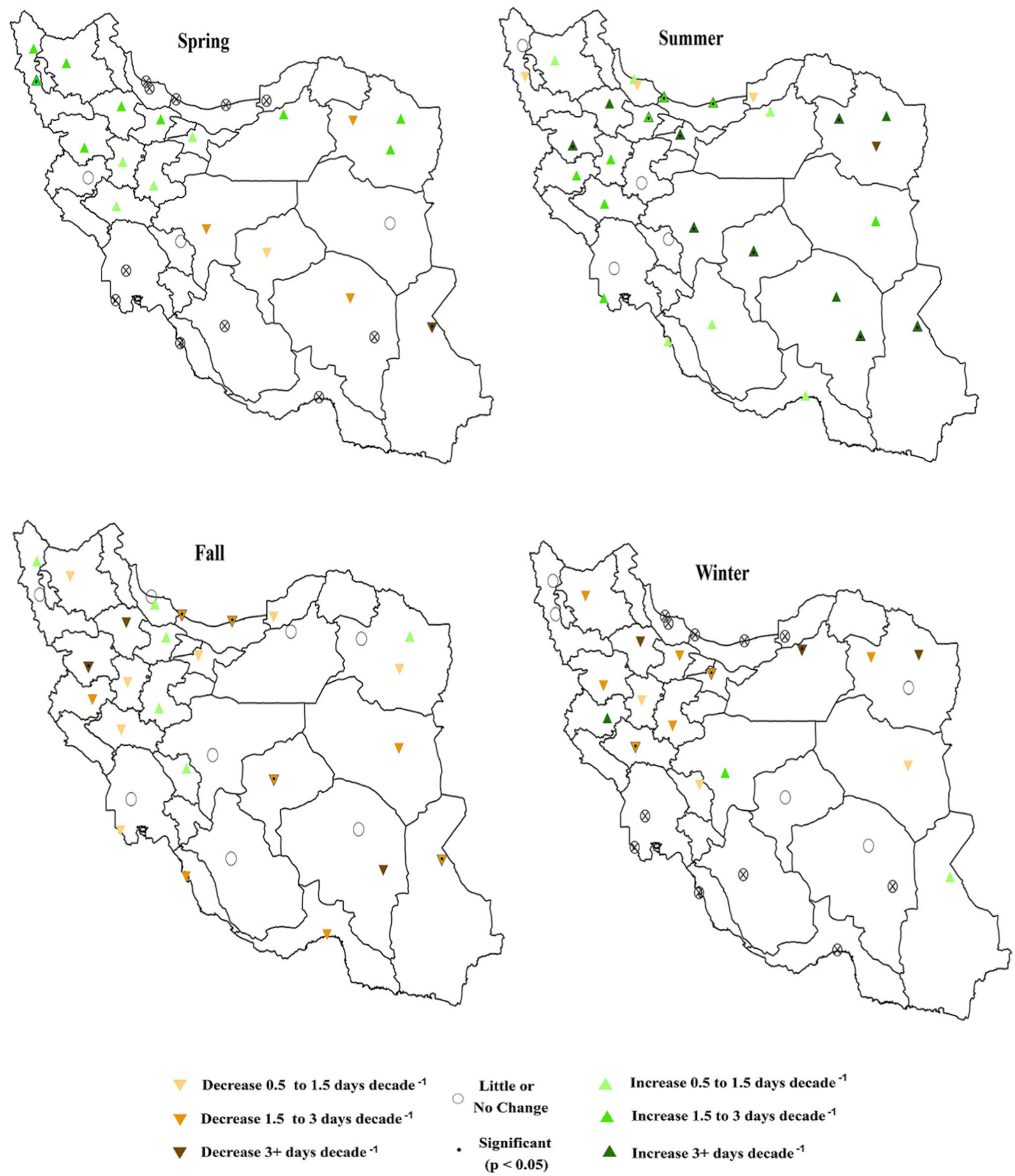

Fig. 4 Mean changes for seasonal duration of Iran (1959–2018). Downward arrows indicate an earlier start date while upward arrows indicate later start dates. Significant values are represented by dots

abnormality in the onset, end, and length of seasons, which has negative outcomes for human activities and ecosystems. Temperature thresholds were used to study seasonal changes, which have been used by other studies, too (Allen and Sheridan 2016). Iran does not have four seasons in all its regions. The southern areas of Iran and flat coastal areas of Caspian

Table 3 Mean onset and length of seasons of climatic regions of Iran (1959–2018)

Climatic region		Elevation(m)	Spring		Summer		Fall		Winter	
			Onset	Length	Onset	Length	Onset	Length	Onset	Length
Temperate	North Coast	−15	–	–	19 May	158	23 Oct	2.7	–	–
Change			–	–	−0.64	0.64	−0.06	−0.83	–	–
Mediterranean	Mountainside (outside)	1148	12 Feb	105	28 May	130	4 Oct	98	7 Jan	32
Change			−2.1	1.2	−0.9	2.25	1.7	−0.92	0.8	−2.79
Cold	Mountainous	1458	4 Mar	103	16 Jun	93	16 Sep	92	16 Dec	77
Change			−2.05	1.79	−0.23	1.43	0.65	−0.66	−0.37	−1.71
Semi-arid	Mountainside (inside)	1299	16 Feb	99	25 May	127	29 Sep	93	28 Dec	47
Change			−1.03	−0.82	−1.85	3.91	2.1	−0.85	1.6	−1.37
Arid	Central	1222	3 Feb	98	12 May	142	1 Oct	94	30 Dec	32
Change			−0.05	−2.12	−2.37	4.46	2.13	−2.68	0.05	0.45
Coastal desert	South Coast	12	–	–	28 Mar	246	28 Nov	119	–	–
Change			–	–	−0.9	0.88	−0.75	−0.95	–	–

A negative trend indicates early onset of the season (reduced duration) and a positive trend indicates delayed onset (increased duration)

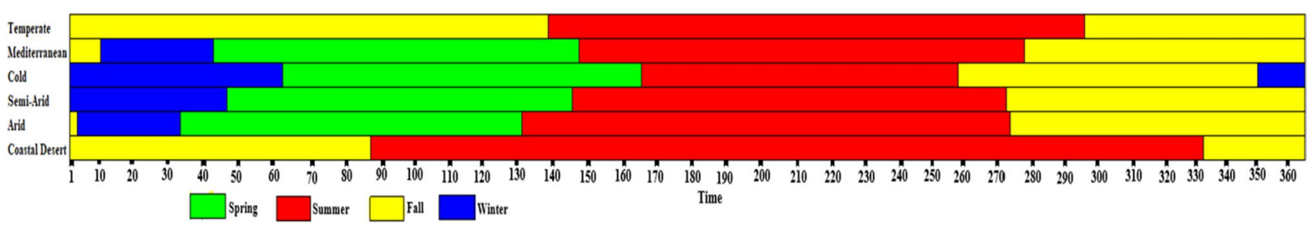

Fig. 5 Mean time of onset, end, and length of seasons in the climatic regions of Iran

Sea have two summer and fall seasons. In the north of Iran, summers are shorter and falls are longer while in the south, the opposite is true. The onset of summers and falls in both climatic regions is delayed, summers are longer, and falls are shorter (Table 3). The increase in the warm period could be due to the poleward expansion of the Hadley circulation in falls and summers, with an expansion of 2 to 4.5 degrees since 1979 (Hu and Fu 2007), which is due to weaker expansion of cold masses from higher latitudes and the stronger role of warm southern masses. Except for the coastal areas, there are four seasons in other regions of Iran inherently, but the onset, end, and duration of seasons in all regions are not homogeneous. In general, from the southeast to the northwest of Iran, the winter is longer and the summer is shorter, respectively, and the high altitude (Mountains of Zagros and Elburz) and latitude play an important role in this spatial distribution. This spatial distribution is in line with the principle of spatial dependence. So, one can say that seasons in western and northwestern Iran are similar to the temperate climates of higher latitude regions (Caucasia), seasons in southeastern regions are like those of dry and hot climates (subtropical), and seasons in northeastern and eastern regions resemble those of dry and cold climates (Turan). The onset, end, and the duration of seasons change in accordance with increases in earth's temperature which are usually accompanied by delayed onset of cold seasons, early onset of warm seasons, reduced duration of the cold seasons, decrease of 1.5 days of winter per decade, and increase of 2.25 days of summer per decade. Moreover, in climatic regions, the onset of fall and winter in dry regions is delayed, and in the semi-arid regions, fall starts later. The greatest decrease in the duration of fall with 2.68 days per decade belongs to dry regions and the decrease of winter with 2.79 days per decade belongs to the Mediterranean climate of the western regions of Zagros. Springs and summers start earlier and last longer, the main reasons of which are global warming and the expansion and displacement of climate belts from the equator to the poles like in the Northern Hemisphere (Schaefer et al. 2005) and Europe (Pena-Ortiz 2015). The arid and semi-arid climatic regions (a major part of Iran) have longer hot and dry seasons and shorter cold seasons (Table 3). This can be related to the changes of climate zones, and hotter and drier climates of short cold periods in different climatic regions of Iran (Raziei 2017). Climate changes increase spatial range of two-season regions in central and southeastern parts of Iran, bordering the Lut Desert. Seasons in these regions will be similar to those of southern Iran which have long seasons and lack winter or cold falls, and the warm desert climatic regions are extended to higher latitudes. These changes show that the climate of Iran is becoming drier and hotter. Part of this is due to the effects of global warming and climate change, which show themselves as decrease in precipitation, severe droughts, mild winters, and decrease in snowfall, extreme heat, and increase in dust storm days. The aggravation of these consequences is related to the direct effects on humans, the increase in the population of cities, land use change, cultivating with underground water, desertification, an increase of dams, and drying wetlands. Most natural ecosystems including flora and fauna change with change of seasons and move to higher altitudes and latitudes. These border climatic regions (semi-arid foothills and semi-humid Mediterranean areas near the highlands) are also more vulnerable to climate and season changes, which are related to the northern expansion of tropical and subtropical climate zones to higher latitudes (Rajaud and de Noblet-Ducoudre 2017). In this study, the effective atmospheric patterns were used for explaining the changes of the seasons, but they did not directly identify the changes of the seasons related to the atmospheric patterns. Investigating this issue, however, will make the season changes clearer.

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Author contribution RD (as the corresponding author) pursued the idea, analyzed all datasets and results, and prepared the draft. BA (second author) studied and revised the manuscript.

Data availability All data used in the study are not freely available online. However, the data that support the findings of this study are available on request from the corresponding author.

The manuscript has not been submitted to more than one journal for simultaneous consideration. The manuscript has not been published previously (partly or in full) unless the new work concerns an expansion of previous work. Our study is not split up into several parts to increase the number of submissions and submitted to various journals or to one journal over time. No data has been fabricated or manipulated.

Declarations

Consent to participate We used only meteorological data for analyzing.

Consent for publication RD accepts the responsibility of releasing this paper and the materials on behalf of all co-authors.

Conflict of interest The authors declare no competing interests.

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