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ORIGINAL PAPER

Extreme temperatures linked to the atmospheric blocking events in Turkey between 1977 and 2016

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Abstract

Extreme maximum (Tx) and extreme minimum temperature (Tn) frequency distributions during summer and winter for blocked conditions were analyzed within Turkey during the period from 1977 to 2016 by using observational data. The Tx (0.5–0.8%) and Tn (0.4–2.0%) frequencies vary between these values for the entire period during summer. However, Tx varies between 0.0 and 1.0, while Tn varies between 0.8 and 2.4 during winter. It is quite clear that atmospheric blocking has a greater cooling effect during winter. The maximum values for Tx and Tn are observed when the block center located within the easternmost sector impacting Turkey for summer. The maximum Tx frequency is observed in association with blocking in the westernmost sector, and the maximum Tn frequency is observed with blocking in the easternmost sector impacting Turkey during the winter season. Block intensity has almost no impact on Tx frequency although it has enhancing effect on Tn frequency during the summer. For winter, block intensity has a decreasing effect on both the maximum Tn and maximum Tx. The maximum Tx and Tn values increase with the block size for the summer. During the winter, the maximum Tx frequency decreases with the increase in the size of a blocking event; however, the greatest Tn frequency is observed within the 0°–30° E sector and lowest within the 30° E–60° E sector. The block duration has an enhancing influence on the maximum Tx value, while maximum Tn is observed during short-duration events and a minimum is observed during moderate-duration events during the summer season. For the winter season, the block duration has a decreasing effect for Tx frequencies and increasing effect for Tn.

Keywords Atmospheric blocking · Extreme temperature · Maximum temperature · Minimum temperature · Turkey

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1 Introduction

Atmospheric blocking (defined as a stationary anticyclone located within the mid-latitudes) plays an important role regional weather patterns. It blocks the regular progression of synoptic-scale cyclones and is associated with stagnant weather over the high-pressure region and surroundings. Thus, blocking can be associated with severe weather such as flash floods, dry spells, or extremely low and high temperatures. It has been widely investigated by researchers using a variety of definitions. These researchers focused on detection methods for blocking events or defining new characteristics of blocking (Lejenas and Okland 1983; Tibaldi and Molteni 1990 (*hereafter TM90*); Lupo and Smith 1995 (*hereafter LS95*); Barriopedro et al. 2006), the climatological characteristics of the blocking (Wiedenmann et al. 2002; Barriopedro et al. 2006), and the influence of atmospheric blocking on climate variables (Antokhina et al. 2016; Whan et al. 2016; Nunes et al. 2017; Sitnov et al. 2017; Efe et al. 2019, 2020).

The impacts of atmospheric blocking on extreme weather events also have been investigated due to their adverse effects on society, agriculture, and the economy. Some of these studies have focused on extreme cold temperatures (Diao et al. 2015; Whan et al. 2016; Sousa et al. 2017), persistent cold spells (Luo et al. 2016; O'Reilly et al. 2016; Brunner et al. 2018), extremely warm temperatures (Rimbu et al. 2014), and extreme precipitation events (Rimbu et al. 2015; Nunes et al. 2017; Sousa et al. 2017; Rabinowitz et al. 2018) as related to blocking.

The effects of blocking on Turkey have not been studied widely. Tayanç et al. (1998) is the first study that mentions blocking for a blizzard event, investigating one of the most famous blizzards that occurred within Istanbul, Turkey, and surrounding regions. They determined that the blizzard was caused by a stationary cyclone which was associated with a dipole-type blocking. Demirtaş (2017) examined the 2012 winter season which was associated with prolonged cold spells in Europe due to an omega-shaped blocking event centered over Siberia and concluded that Turkey experienced a cold wave event that persisted anywhere from 4 to 18 days, depending on the location within the country. One of the most recent studies, Efe et al. (2020) investigated the influence of blocking on temperatures for different blocking features during all seasons in Turkey. They concluded that blocking plays a crucial role on the temporal distribution of mean temperatures even though the blocking frequency is around 30%. Efe et al. (2019) examined the impacts of blocking on precipitation within Turkey. They found that blocking results in a greater mean precipitation frequency all across the country and this increase varies between 12 and 42%.

There are several studies focused on extreme events in Turkey. Yesilırmak and Atatanır (2016) examined the precipitation concentration in western Turkey by using several indices and concluded that mostly nonsignificant decreasing trends of precipitation concentration were observed for all indices. Kömüşçü and Çelik (2013) studied the Marmara flood that took place in 2009. They emphasized that, in addition to the favorable meteorological conditions, urbanization played a major role for the worst flooding that occurred in the region in recent decades. Unal et al. (2013) investigated several summer heatwaves over western Turkey from 1965 to 2006 and concluded that these phenomena increased within this period. Deniz and Gönençgil (2015) examined the trends in summer daily maximum temperatures for Turkey 1970–2006. They demonstrated that 59% of the stations have an increasing trend in the frequency of warm, hot, and extremely hot days at the 0.05 confidence level or greater. On the other hand, 34% of the stations have a significant decreasing trend in the frequency of cool, cold, and extremely cold days. Toros (2012) analyzed the maximum temperature (Tx) and minimum temperature (Tn) during winter as well as summer. He found that there has been significant warming in both annual maximum and minimum temperature observations, and the summer season trends have been stronger than those during the winter season. Most recently, Baltacı et al. (2017) conducted research on the effects of teleconnection patterns on the extremes of temperature and precipitation. They found that strong positive and negative temperature anomalies can be explained by the impact of the Arctic Oscillation and the East Atlantic–West Russian pattern on the jet stream.

Briefly, the scope of this study is to investigate comprehensively the influence of atmospheric blocking and its parameters on the Tx and Tn frequency distribution for the summer and winter seasons. This is the first study that examines the relationship between atmospheric blocking and extreme temperatures for Turkey. It is also unique due to the consideration of the block intensity (BI) characteristic that is used by this research group. The data used for blocking and extreme temperatures and methodology are described in the next section. The general distribution of Tx and Tn frequency for both the summer and winter seasons during blocked days and the changes in the distribution of Tx and Tn frequency with respect to different blocking characteristics are presented in Sect. 3. The results are summarized in Sect. 4.

2 Data and methodology

2.1 Data

The 500 hPa geopotential height fields were retrieved from the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) Reanalysis dataset (Kalnay et al. 1996). These data are favorable to use for the detection of blocking events and have been used for this purpose by several studies (e.g., Mokhov et al. 2014; Sitnov et al. 2014; Efe et al. 2019; Lupo et al. 2019). There are several data types available for both the surface and on mandatory pressure levels with 6-h temporal and 2.5°×2.5° spatial (latitude–longitude) resolution. The dataset has a temporal coverage from 1948 to the present. The daily 500 hPa geopotential height data from the NCEP–NCAR Reanalysis at 0000 UTC were used in this study for the period of January 1, 1977–December 31, 2016. The study domain was selected to cover 20° W–90° E and 30° N–90° N, capturing all the blocking events that can affect Turkey (e.g., Efe et al. 2019).

The location of the stations used in this study is presented in Fig. 1. The daily minimum and maximum data for summer and winter for these 77 stations located across all regions of Turkey were obtained by the Turkish State Meteorological Service. The data are continuous for all stations from January 1, 1977, to December 31, 2016. These 77 stations have been used by Efe et al. (2019, 2020), and they represent all seven regions of country.

2.2 Methodology

2.2.1 Blocking and its characteristics

The study of TM90 described a one-dimensional (1-D) blocking detection method. Using this method, two geopotential height gradients: the Geopotential Height Gradient for the part South of a base latitude (GHGS) and the Geopotential Height Gradient for the part

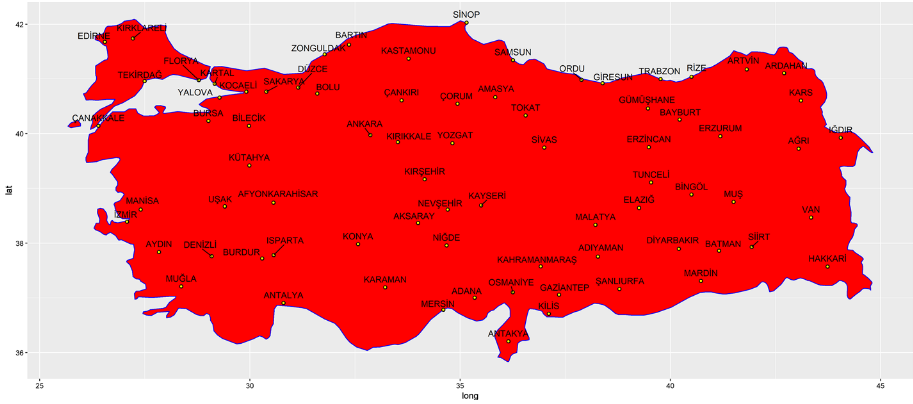

Fig. 1 Location of the stations used in this study

North of a base latitude (GHGN), for each longitude are calculated by using a base or reference latitude. (The method is also applied to the first grid points south and north of the base latitude.) Barriopedro et al. (2006) modified this method by using a different latitude for northern gradient and different increments based on the availability of NCEP–NCAR reanalysis data. More details regarding this methodology can be found in TM90 and Barriopedro et al. (2006).

Any longitude is accepted as blocked when both GHGS and GNGN verify the condition expressed by (1) for at least one of five latitudes (the base, two south of the base, and two north of the base):

$$\mathrm{GHGS} > 0$$

$$\mathrm{GHGN} < -10\ \mathrm{gpm}/^{\circ}\mathrm{lat}$$

$$\text{The anomaly of geopotential height at a given latitude and longitude } > 0 \tag{1}$$

Five (12.5° longitude) or more contiguous grid points are required to satisfy the criteria described in (1) simultaneously, with the allowance of one non-blocked longitude between the blocked longitudes to verify the minimum longitudinal extent. The minimum duration criteria are five days as used by most authors (e.g., Treidl et al. 1981; LS95; Shabbar et al. 2001; Scherrer et al. 2006). The definition of BI is adopted from Wiedenmann et al. (2002) with a different block center and block box definition, and temporal algorithm to track blocking used in this study is also described in Barriopedro et al. (2006).

2.2.2 Temperature and statistical analysis

The extreme cold temperature (Tn) for each season is defined as the minimum temperature that is lower than the first percentile of all minimum temperature values during winter (December, January, and February) and summer (June, July, and August). The extreme warm temperature (Tx) for each season is defined as the maximum temperature that is greater than the 99^{th} percentile of all maximum temperature values for the aforementioned season. This represents temperature values that are three standard deviations from the mean since temperature is generally normally distributed (e.g., Nunes et al. 2017 and references therein). The frequency of extreme events during blocking is calculated as the ratio between the number of days with extreme events to the total number of blocking days. The Standard Normal Homogeneity Test (SNHT) is used to check the temporal homogeneity of the data for selected stations.

The frequency of extreme events was examined as related to the characteristics of atmospheric blocking events. The study domain is divided into four sectors: 20° W–0° E (hereafter S1), 0°–30° E (hereafter S2), 30°–60° E (hereafter S3), and 60°–90° E (hereafter S4), respectively, to be consistent with Efe et al. (2019, 2020). The BI is divided into three sub-categories, weak, moderate, and strong, as described in LS95. The block duration and block size are divided into three sub-categories by using percentiles: short term (small) for the values smaller than the 25th percentile, moderate (moderate) for the values between 25th and 75th percentile, and persistent (large) for the values greater than the 75th percentile. All figures were illustrated via the ggplot2 R-package (Wickham 2016). All calculations are done using R-programming (R Core Team 2018; Wickham et al. 2018).

3 Results

3.1 Blocking climatology

The statistical properties for atmospheric blocking events during the study period and within the study domain are shown in Table 1. The mean occurrence frequency for blocking events was 11.7 events per year, while it was 2.7, 3.9, 2.5, and 2.6 for winter, spring, summer, and fall, respectively. The mean BI was 2.65, 2.31, 1.91, 2.36, and 2.65 for seasons in the same order and annual, respectively. The mean size of the blocking events in winter season was greater than other seasons with the value of 29 degrees of longitude. The following seasons have blocking widths of 27, 25, and 25 degrees longitude, and the annual mean block size was 28. Lastly for the blocking durations, the annual mean persistence for all blocking events was 8.8 days, while it was 9.2, 9.2, 8.4, and 8.1 for the seasons in the same order. These statistics were used to inform the analysis below.

3.2 Time variability of indices

In this section, the trends and variability of Tx and Tn for both the summer and winter seasons are investigated here. The annual mean number of Tx and Tn days is calculated by averaging the number of Tx and Tn days for all stations during the seasons shown in Fig. 2. There was no statistically significant trend or variability detected during the summer and winter for both Tx and Tn days. The magnitude of correlation coefficient between time and temperature indices is smaller than 0.2, meaning that there is no relationship between

Table 1 The statistics of the blocking events for study period and domain

	Winter	Spring	Summer	Fall	Annual
Frequency	2.7	3.9	2.5	2.6	11.7
Intensity	2.65	2.31	1.91	2.36	2.41
Size (longitudes)	29	27	25	25	28
Duration (days)	9.2	9.2	8.4	8.1	8.8

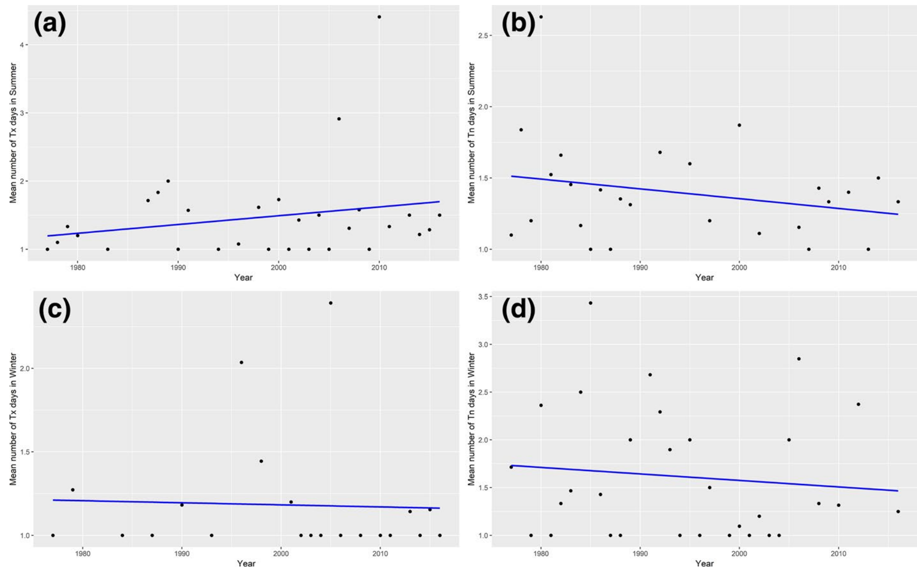

Fig. 2 The national average for annual **a** Tx days in summer, **b** Tn days in summer, **c** Tx days in winter, and **d** Tn days in winter

temperature indices and time. The correlation coefficient is calculated using 30 data points (thus, df = 30 − 2 = 28). The critical values for statistical significance at $p = 0.05$ (adapted from critical values of t distribution) associated with df = 28 are −0.305 and 0.305. The correlation coefficients here are between these critical values, and as such the trends are not significant.

Efe et al. (2020) investigated the relationship between atmospheric blocking and daily mean temperature for the same period and the same stations during all seasons. The northwest part of Turkey experiences negative temperature anomalies during all seasons in association with blocking. The western part of the country experiences very strong, strong, or near-normal negative temperature anomalies; the central part experiences near-normal negative anomalies at most stations. The eastern part of the country has near-normal temperature anomalies which is consistent with the location of blocking. In the following subsections, the impact of atmospheric blocking on extreme temperatures for summer and winter season is going to be investigated below.

3.3 Summer season

3.3.1 All data

The mean Tx (Tn) distribution during summer is shown in Fig. 3 (Fig. 4). The Tx (Tn) values fluctuate between 0.5 (0.4) and 1.8 (2.0) across the country. The southernmost part of the country (the area in the Marmara Region, an area in the Central Anatolia Region, and an area in the northwest of the country) has extreme minimum mean Tx (Tn) values lower than 0.6 (0.7)%. The western part of the country and Black Sea coastline (the Central Anatolia Region, Black Sea Region, and the inner parts of all regions) have Tx (Tn) values

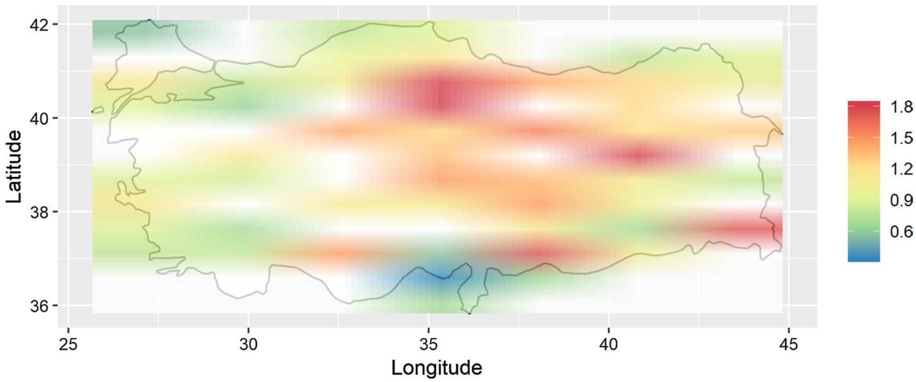

Fig. 3 The Tx frequency distribution during blocked days in summer

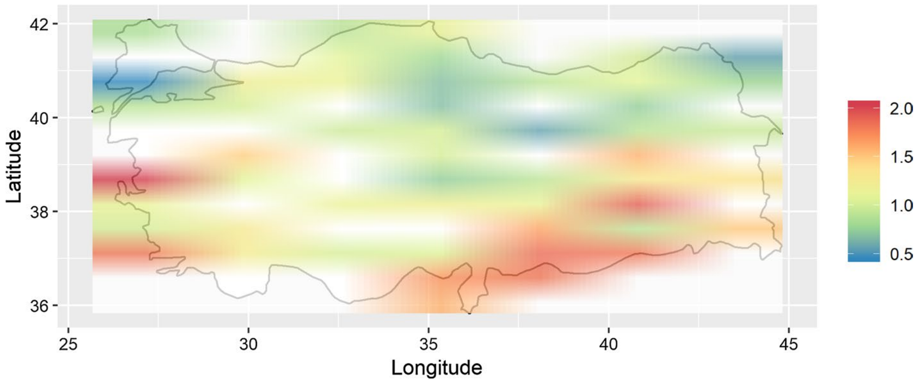

Fig. 4 The Tn frequency distribution during blocked days in summer

around 1.0% (fluctuates between 0.9 and 1.7%). The remainder of the Anatolia Region, some parts of southern Turkey, and areas in the Aegean Region have both Tx and Tn frequencies near 1.5% (Figs. 3, 4). In general, blocking has a larger impact on both Tx and Tn frequency in the summer. However, the areas with a higher frequency of maximum Tx and maximum Tn differ. The central regions have greater Tx distributions, while the outer regions have greater Tn distributions during blocking events.

3.3.2 Block center

In this section, the Tx (Tn) frequency distribution for the block center location during summer is examined (Fig. 5). During the summer season, only one blocking event was located in S1. So, S1 was removed for the summer season results. When the block center is located in S2, the Tx (Tn) frequency values have a minimum and maximum of 0.0 (0.0) and 1.8 (3.3). The extreme eastern part of the country, an area from central Turkey, and the most western part of the country (the Aegean Region and the Southeast Anatolia Region) have the greatest Tx (Tn) frequency values, while the rest of the country (an area that includes some parts of Black Sea, Marmara and Aegean Region and the rest of the country) have values around 0% (around 2.0 and below 1.0%, respectively) (Fig. 5a, b). The Tx (Tn)

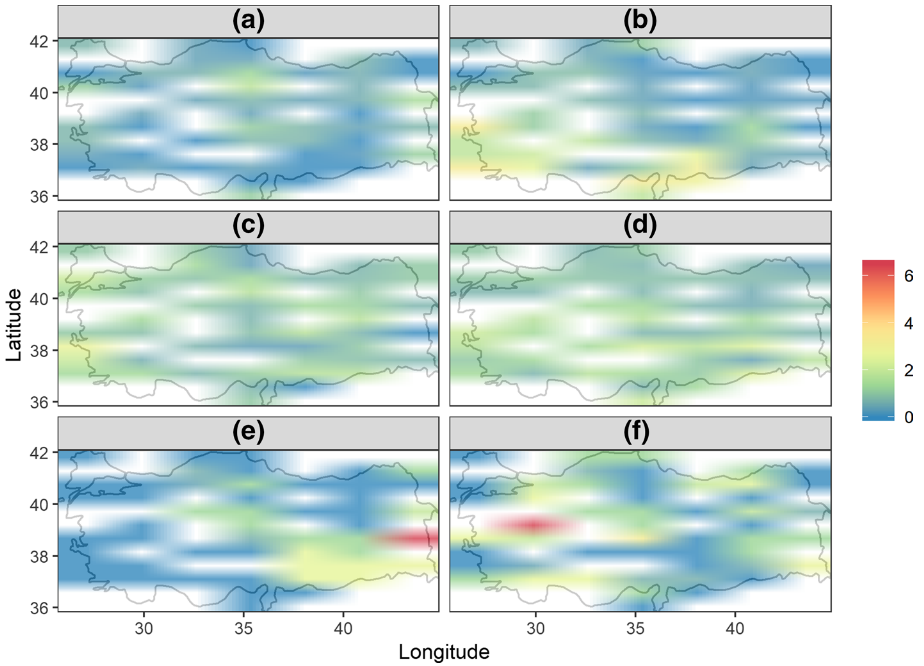

Fig. 5 The Tx frequency distribution for; **a** S2, **c** S3, and **e** S4, and Tn for; **b** S2, **d** S3, and **f** S4, during summer season blocked days

frequency values have a range of 0.0 (0.3) and 2.7 (2.4)% when the block center is located in S3. The area around İzmir (the belt around 38° N latitude bounded between 37 and 40° E longitudes) has the greatest Tx (Tn) frequency. Minimum Tx (Tn) frequency values are observed over a large area in center, an area in southeastern part of the country, and an area over the most northern part of the country (over the area in the northeast Anatolia and an area in the south East Anatolia Region) (Fig. 5c, d). For S4, the Southeastern Anatolia Region (several yellow shaded areas across Turkey) has the greatest mean Tx (Tn) frequency, approximately 2.0 (2.7)% with the maximum value of 6.4% at Van (inner part of the Aegean Region with the value of 6.4%). Areas in the center of the country and in the northeastern part of the country (several areas (green shaded) across the country) have a Tx (Tn) frequency value around 1.2 (2.0)%, while the rest of the country has a Tx frequency below 0.5 (0.5)% (Fig. 5e, f).

3.3.3 Block intensity

The mean Tx (Tn) frequency distribution stratified by BI during summer is shown in Fig. 6. The BI is divided into three categories as stated in Sect. 2. However, there were no summer season blocking events classified as strong. The Tx (Tn) frequency fluctuates between 0.0 (0.0) and 2.5 (1.2)% for blocking event classified as weak. The area in the Marmara Region, the area around İzmir, and the area around Hatay (central Anatolia Region) have the greatest Tx (Tn) frequency. The inner parts of the Marmara, Ege, and Mediterranean Region (the inner parts of the Mediterranean Region and the

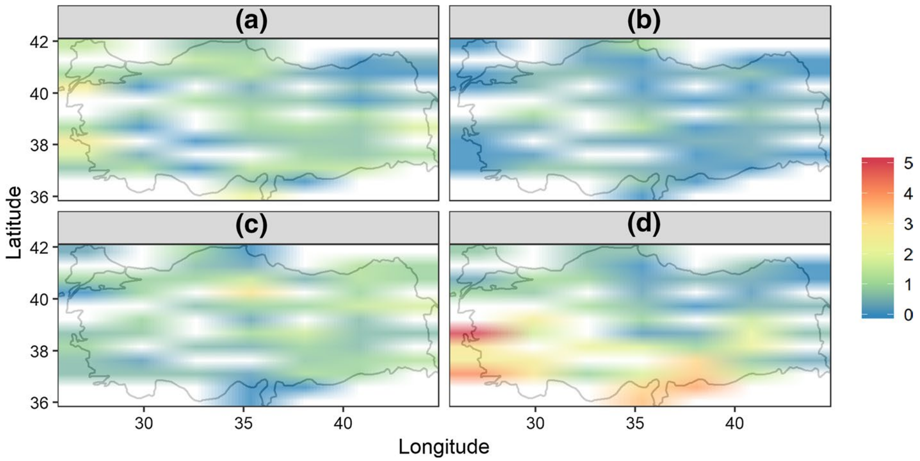

Fig. 6 The Tx frequency distribution for; **a** weak BI and **c** moderate BI, and Tn for; **b** weak BI and **d** moderate BI during blocked days in the summer season

southeastern part of the country) have Tx (Tn) values below 0.5 (0.5)% (Fig. 6a, b). The minimum mean Tx (Tn) distribution is 0.0 (0.0), and the maximum is 2.8 (5.0) when the block intensity is moderate. The area around Çorum (southwestern and southernmost part of the country with the maximum) has the greatest Tx (Tn) frequency, while areas in the most southern and northern parts of the country (the rest of the country) have lowest frequencies (Fig. 6c, d).

3.3.4 Block size

The Tx (Tn) frequency distribution for different block sizes during the summer is shown in Fig. 7. The Tx (Tn) values vary between 0.0 (0.0) and 3.9 (2.4)% when the blocks have small sizes. The area in the eastern part of the country (the most southeastern part of the country) has the greatest Tx (Tn) frequency. The eastern half of the Black Sea coastline, an area in the Marmara Region, and an area of the southern Mediterranean (greater part of the East Anatolia Region, the South Anatolia Region, the vast majority of the Mediterranean Region, and a large fraction of the Aegean Region) have lowest Tx (Tn) frequencies (Fig. 7a, b). When the block size is moderate, the minimum of Tx (Tn) frequency is 0.0 (0.2), while the maximum is 2.8 (2.0)%. The zone from north to the south along the center of the country and an area in the Marmara Region with the maximum around Gaziantep (the continental part of the Aegean Region) have greatest Tx (Tn) values. The southernmost part of the country (the northwestern part of the Marmara Region, a great area in the Central Anatolia Region, and part of the East Anatolia Region) has the minimum Tx (Tn) value of 0.0 (0.2)% (Fig. 7c, d). The Tx (Tn) frequency has a minimum and maximum of 0.0 (0.0) and 1.2 (5.6)%, respectively, for the large-sized block events. The eastern Black Sea coastline and part of the East Anatolia Region (the South Anatolia Region, an area over the East Anatolia Region, and areas over the Aegean Region) have the greatest Tx (Tn) values > 1.0 (4.0)%. The rest of the country (blue-shaded areas over the northern part of the country) has values < 0.8 (1.0)% of Tx (Tn) frequency values (Fig. 7e, f).

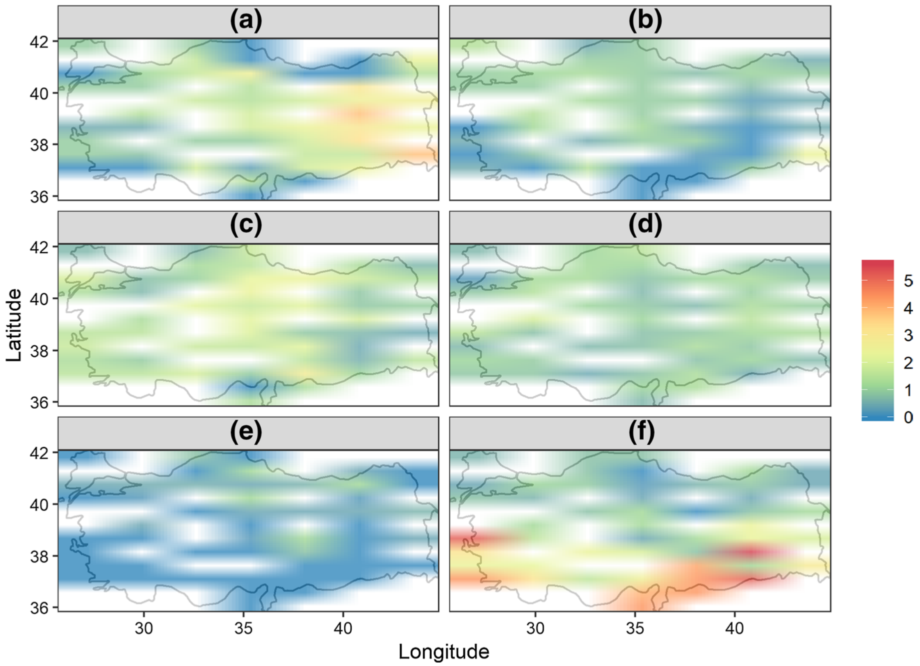

Fig. 7 The Tx frequency distribution for; **a** small, **c** moderate, and e. large blocks, and the Tn for; **b** small, **d** moderate, and **f** large blocks, during blocked days in the summer season stratified by the block size

3.3.5 Block duration

The Tx (Tn) frequency distribution stratified by block duration during summer is shown in Fig. 8. The Tx (Tn) frequency varies between 0.0 (0.6) and 2.6 (6.0)% for the short-duration blocking events. Tx and Tn distributions are almost totally opposite during short-duration blocking events. The vast majority of the country (only the northeast part of the country) has Tx (Tn) values around zero (below 0.5)% for short-duration events. An area in the Marmara Region (areas in the southeastern and southernmost parts of the country) has a maximum Tx (Tn) frequency of 2.6 (over 5.8%)%. There is a zone from the Black Sea to South East Anatolia passing through Central Anatolia (the outer areas of the country) that has a Tx (Tn) value greater (greater) than 1.0 (3.0)%. The Mediterranean Region, the Aegean Region, and a large part of the East Anatolia Region (the rest of the country) have the Tx (Tn) value around zero (< 2.0)% (Fig. 8a, b). For the moderate-duration blocking events, Tx (Tn) frequency has a minimum and a maximum of 0.0 (0.0) and 2.2 (2.2)%, respectively. An area in the northern part of Central Anatolia Region (an area in the southwestern part of the country) has the maximum Tx (Tn) frequency values. Areas in the southernmost and northern parts of the country (the northern part of the country, Central Anatolia Region, and East Anatolia Region) have the minimum Tx (Tn) of 0.0% (Fig. 7c, d). The minimum Tx (Tn) frequency is 0.0 (0.5)% and the maximum is 3.5 (2.7)% for the most persistent blocking events. An area in the East Anatolia Region (an area in the southeast Anatolia Region (yellow shaded))

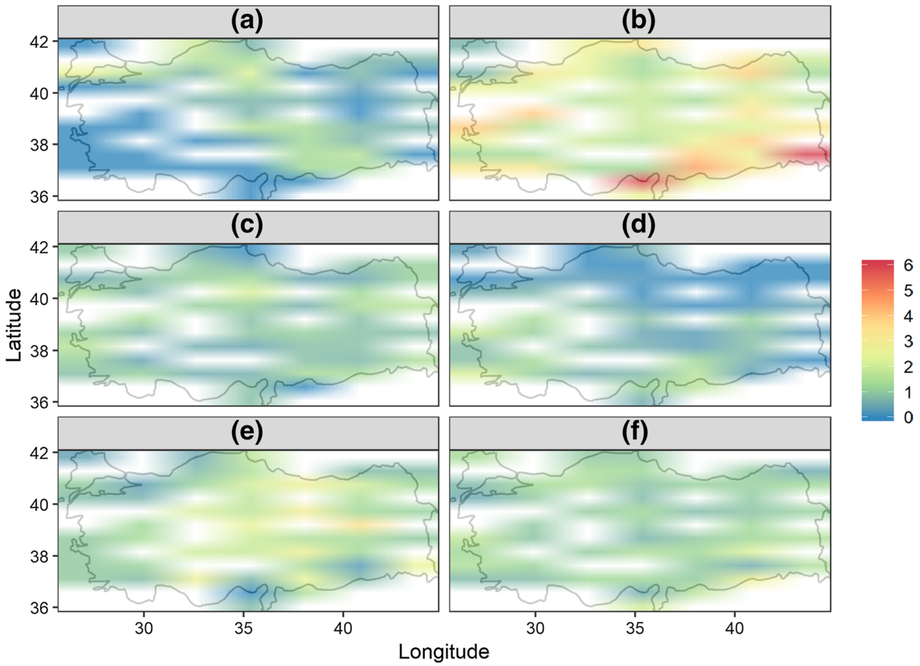

Fig. 8 The Tx frequency distribution for; **a** short-lived, **c** moderate, and **e** most persistent blocks, and Tn for; **b** short-lived, **d** moderate, and **f** most persistent blocks, during blocked days in the summer season

has the maximum of 3.5 (2.7)%, while the area in the southernmost part of the country (several areas (blue shaded)) has the minimum of 0.0 (0.5)% (Fig. 8e, f).

3.4 Winter season

3.4.1 Whole data

The mean Tx (Tn) distribution during the winter season is shown in Fig. 9 (Fig. 10). The Tx (Tn) values fluctuate between 0.0 (0.8) and 1 (2.4) across the country. The central Black Sea Region, areas in the Central Anatolia Region, areas in the Aegean Region, and an area in the northeastern part of the country (areas in the most southern and southeast part of the country) have the minimum mean Tx (Tn) values lower than 0.2 (1.0)%. Almost all East Anatolia Region (almost all Anatolia) has the Tx (Tn) values < 0.7 (that fluctuates between 1.0 and 1.8)%. A small portion of southeast Anatolia, East Anatolia, and Mediterranean Region (the Trace Region, east Black Sea coastline, and a small part of the Central Anatolia) have Tx (Tn) values > 0.7 (1.8)%. Thus, blocking has a larger impact for Tn distribution although it has a lesser impact for Tx during the winter season overall.

3.4.2 Block center

In this section, the Tx (Tn) frequency distribution for different sectors of blocking activity during winter is examined. The Tx (Tn) frequency distribution is shown in Fig. 11.

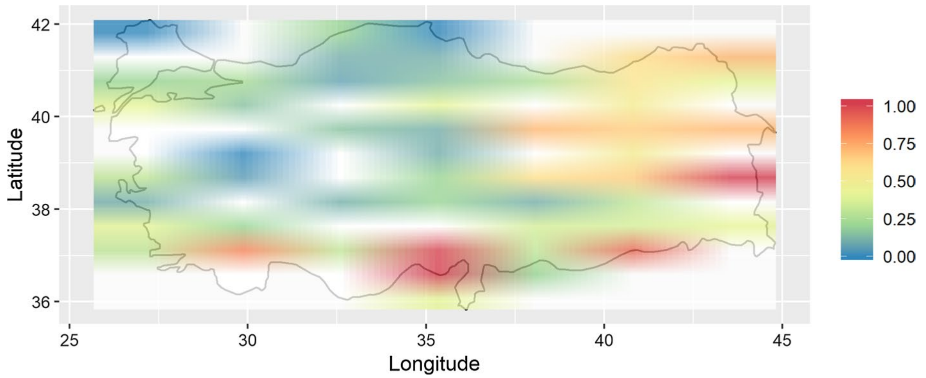

Fig. 9 As in Fig. 3, except for blocked days in winter

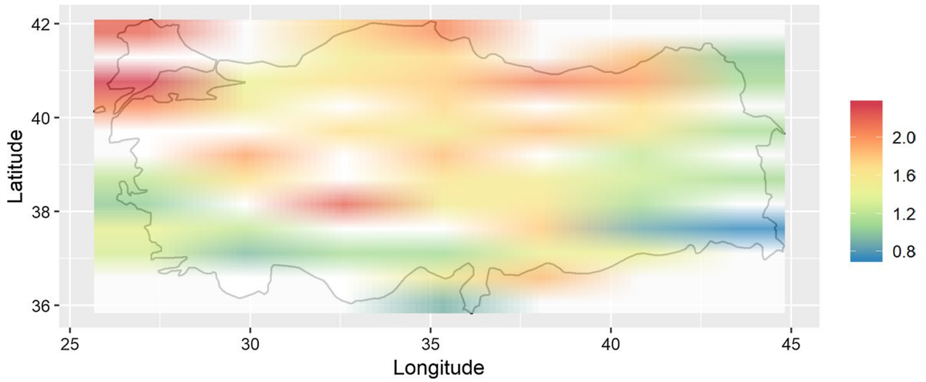

Fig. 10 As in Fig. 4, except for blocked days in winter

The Tx (Tn) values fluctuate between 0.0 (0.0) and 5.3 (1.4)% when the block center is located in S1. Areas in the South East Anatolia Region and the Mediterranean Region (an area in the southwest part of the country) have the maximum Tx (Tn) frequency with the value of greater than (around) 5.0 (1.4)%. The western part and some areas across the country (the rest of the country) have minimum Tx (Tn) values around (smaller than) 0 (0.6)% (Fig. 11a, b). When the block center is located in S2, Tx (Tn) frequency values have a minimum and maximum of 0.0 (0.1) and 1.0 (2.5)%, respectively. An area in the East Anatolia Region (the southern and northern parts of the country except Marmara Region) has the greatest Tx (Tn) frequency values, while the rest of the country (inner parts of the country) has values below 0.7 (1.0)% (Fig. 11c, d). The Tx (Tn) frequency values have a range of 0.0 (0.4) and 1.8 (5.9)% when the block center is located within S3. An area over the eastern part of the country (areas in the Marmara Region and around Sinop) has the greatest Tx (Tn) frequency. Minimum Tx (Tn) frequency values, < 0.5 (around 0)%, are observed over the rest of the country (over a small area in the northeast Anatolia and the Mediterranean Region) (Fig. 11e, f). In S4, a small area in the east of the Black Sea Region (the area in the East Anatolia Region) has the greatest mean Tx frequency around 0.8 (6.0)%. The rest of the country (the western part of the country, an area in the East Anatolia Region, and several areas in

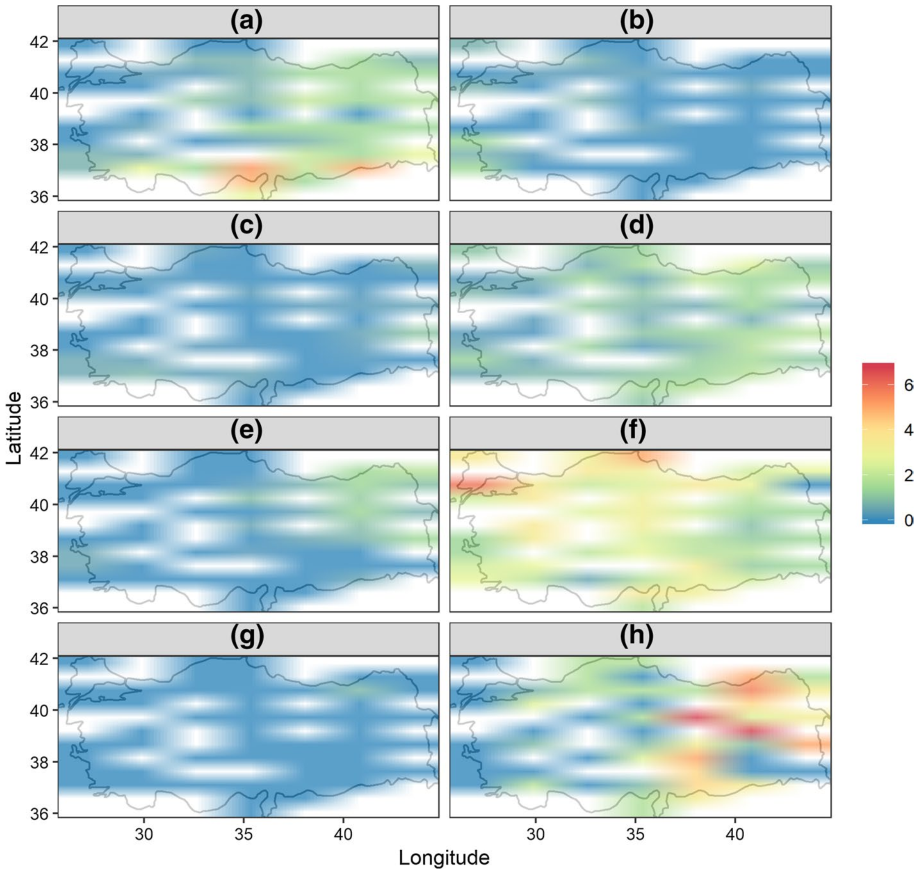

Fig. 11 As in Fig. 5, except for the winter season

the Central Anatolia) has the minimum Tx (Tn) frequency value of exactly (below) 0.0 (0.5)% (Fig. 11g, h).

3.4.3 Block intensity

The mean Tx (Tn) frequency distribution stratified by BI during winter is shown in Fig. 12. The Tx (Tn) frequency fluctuates between 0.0 (0.0) and 4.9 (6.1)% during the weak blocking events. Areas in the southwestern part of the country and around Hatay (northern part and several areas across the country) have the greatest Tx (Tn) frequency. The rest of the country except southern parts (the inner parts of the Mediterranean Region and an area in southeastern part of the country) has Tx (Tn) values below 1.5 (1.0)% (Fig. 12a, b). The minimum mean Tx (Tn) frequency is 0.0 (0.0) and the maximum is 1.5 (1.8) when the BI is moderate, respectively. The area over the northeastern part of the country (the southern part of the country) has the greatest Tx (Tn) frequency, while the rest of the country (the rest of the country) has lower frequencies (Figure 12c, d). The Tx (Tn) frequency distribution during strong blocking events is shown in Fig. 12e (Fig. 12f). The entire country (almost the entire country with a few exceptions) has the value of 0%. (An area around

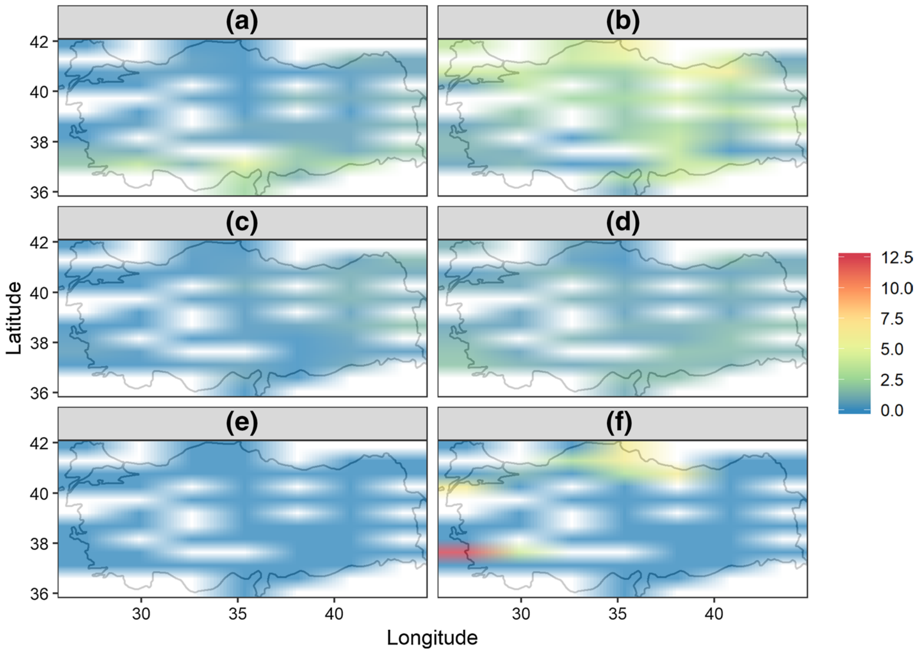

Fig. 12 As in Fig. 6, except for the winter season

Aydın has a Tx value of 12.5% and areas in Black Sea coastline and around Çanakkale have a Tx value of 6.25.)

3.4.4 Block size

The Tx (Tn) frequency distribution for different block sizes for winter is shown in Fig. 13. The Tx (Tn) values change between 0.0 (0.0) and 3.4 (2.9)% when the blocks have small sizes. Areas in the eastern and southern parts of the country (the eastern part of the country and the Southeast Anatolia Region) have greatest Tx (Tn) frequencies. The central part of the Black Sea coastline, the Central Anatolia Region, and the Aegean Region (the area in the Marmara Region and the zone from Black Sea Region to the Mediterranean Region) have lowest Tx (Tn) frequencies (Fig. 13a, b). When the size is moderate, the minimum of Tx (Tn) frequency is 0.0 (0.2), while the maximum is 1.1 (3.2)%. Areas in the East Anatolia Region and in the southwestern part of the country (the area at the intersection of the Central Anatolia and Mediterranean Region) have greatest Tx (Tn) values. The rest of the country (areas in the southeastern and southwestern part of the country) has the minimum Tx (Tn) value of 0.0 (below 0.5)% (Fig. 13c, d). The Tx (Tn) frequency has the minimum and maximum of 0.0 (0.7) and 1.0 (2.2)%, respectively, for the large-sized block events. Several areas in the southern part of the country (the Trace part of the Marmara Region and part of the continental Mediterranean Region) have the greatest Tx (Tn) values > 0.8 (2.0)%. The rest of the country (the southwest part of the Aegean Region, the south part of the Mediterranean Region, and area in the southeast part of the country) has values < 0.5 (1.0)% of Tx (Tn) distribution (Fig. 13e, f).

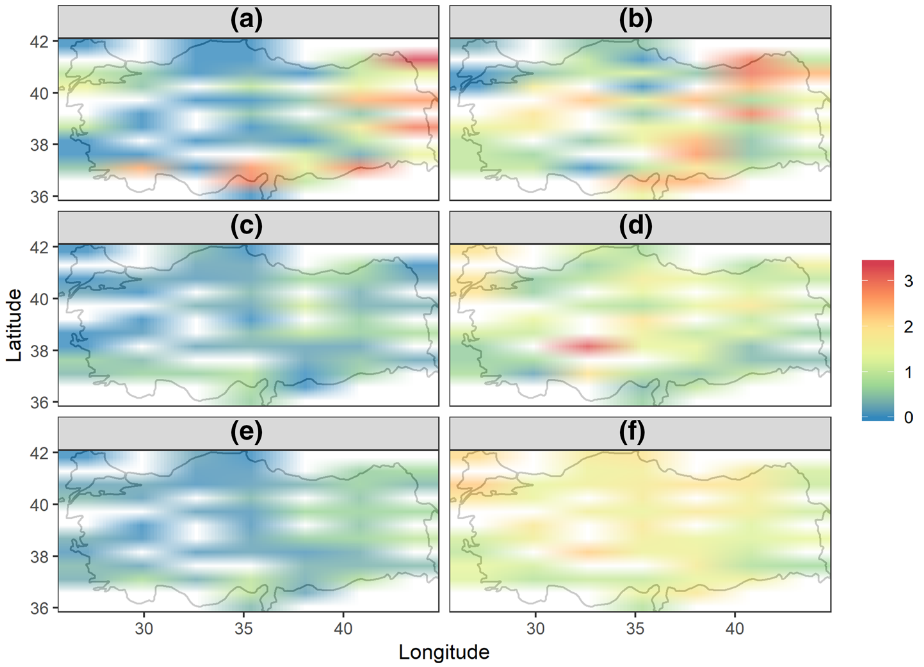

Fig. 13 As in Fig. 7, except for the winter season

3.4.5 Block duration

The Tx (Tn) frequency distribution stratified by block duration during winter is shown in Fig. 14. The Tx (Tn) frequency fluctuates between 0.0 (0.0) and 4.0 (2.0)% for the short-lived blocking events. An area in East Anatolia Region (the area in southeast Anatolia Region) has a maximum Tx (Tn) frequency of 4.0 (2.0)%. The rest of the East Anatolia Region and the Mediterranean Region (several areas across the country) have Tx (Tn) values greater (smaller) than 1.3 (1.0)%. The Aegean Region, Black Sea Coastline, and the vast majority of the Marmara Region (the rest of the country) have the Tx value around 0% (Fig. 14a, b). For the moderate-duration blocking events, Tx (Tn) frequencies have a minimum and a maximum of 0.0 (0.5) and 1.4 (2.8)%, respectively. An area in the southernmost part of the Mediterranean Region (areas in the Marmara Region, in the northern part of the Black Sea Region and in the Central Anatolia) has the maximum Tx (Tn) frequency values. The west part of the country, the Central Anatolia Region, the Black Sea coastline, and an area from southeast Anatolia Region (areas in the southern part East Anatolia and the northern part of the Central Anatolia Region) have the minimum of zero (0.5)% (Fig. 14c, d). The minimum Tx (Tn) frequency is 0.0 (0.5)%, and the maximum is 0.8 (3.8)% for long-lasting blocking events. Areas in the Aegean and Marmara Regions (an area in the intersection of the East Anatolia and Central Anatolia Region) have a maximum of 0.8 (3.8)%, while the rest of the country except several small areas (the area in the southernmost part of the country) has a frequency of 0.0 (0.0)% (Fig. 14e, f).

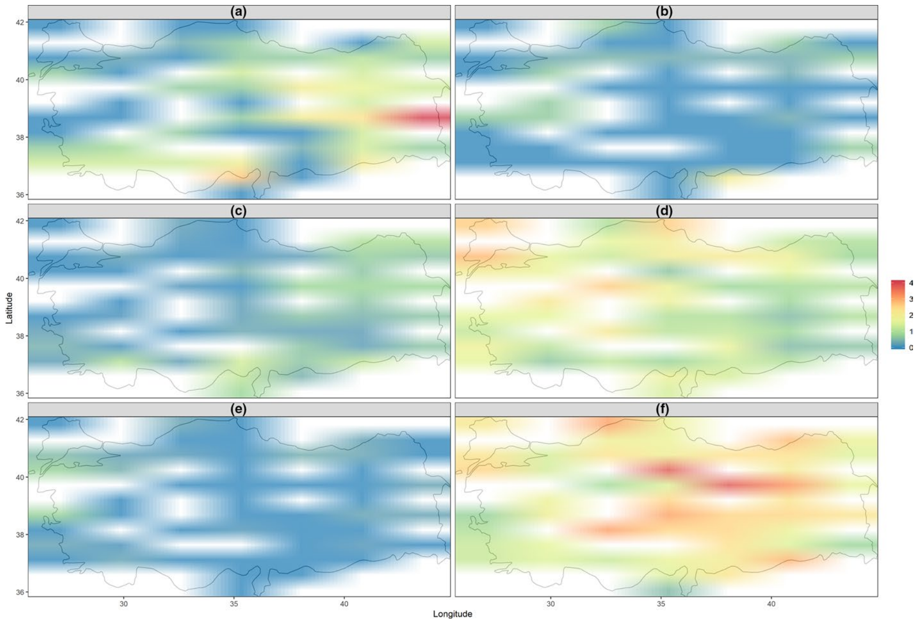

Fig. 14 As in Fig. 8, except for the winter season

3.5 The transition seasons

In this subsection, the general distribution of Tx and Tn for blocking days during the spring and fall is reviewed briefly (not shown) since these were similar to those of the solstice seasons.

During the spring, the minimum and maximum of Tx frequency are 0.4 and 1.7, which is consistent with the winter and summer season values. The spatial distribution for Tx is similar to the winter season during spring. The Tn frequency during the spring season fluctuates between 0.8 and 1.6, and these values are also consistent with the summer and winter values. Additionally, the spring Tn pattern is similar also to that of the winter season.

For the fall season, the minimum and maximum of Tx frequency are 0.1 and 1.3. Both the lower and upper limits are between those of the winter and summer seasons. The spatial distribution of Tx is similar to the summer season. The Tn frequency during fall fluctuates between 0.4 and 2.3, and these values are also between those for the summer and winter seasons. The spatial pattern for the fall Tn pattern is more similar to that of the winter season.

4 Summary and conclusions

The impact of blocking and its characteristics on extreme warm and cold events during the summer and winter seasons are examined in this study. The datasets used were the NCEP–NCAR Reanalysis data for blocking events and observational data for temperatures obtained from the Turkish State Meteorological Service. The study domain and period are consistent with Efe et al. (2019, 2020).

First, the Tx and Tn frequency distributions for the entire period and across the country were examined. During the summer season, the distribution for both extremes fluctuates between 0.5 and 1.8% for Tx and 0.4–2.0% for Tn. Thus, there is a slightly greater spread for the frequency of Tn than for Tx. However, lower frequency values are observed over larger areas for Tn when compared to Tx. During the winter, the cooling effect of blocking is quite evident. The Tx distribution fluctuates between 0 and 1%, that means most of the country observes fewer Tx events during blocking than during non-blocked conditions. Brunner et al. (2018) also demonstrated that blocking has the strongest impact on cold spells on winter. There is a latitudinal pattern present, i.e., for a higher latitude a lower frequency of Tx was observed. On the other hand, the minimum Tn frequency was 0.8 and the maximum was 2.4. There was a counter-latitudinal pattern for the Tn distribution compared to Tx. This means the northern part of the country has greater Tn values, while the southern part has lower. This is likely due to arctic air transport associated with cold advection over Turkey during winter events as reported in Efe et al. (2020).

Secondly, the impact of blocking center location with respect to Tx and Tn distribution was examined. The values of the lower and upper boundaries of Tx occurrence frequency increase when the mean block center moves from west to east. In S4, the maximum value reaches 6.4%. However, there were large areas with small Tx frequency values for S2 and S4 that need to be considered. The lower bound of Tn frequency also increased with the movement of the blocking center location, similar to Tx. However, the maximum Tn value for S1 was greater than that for S2. Similar to Tx distribution, the spatial distribution for low frequencies is obvious when blocking was located in S2 and S4. For summer, if the block center is located further east the Tx frequency values decrease and the area covered by lower values increases. When the block center is located within S1, the maximum Tx value is 5.3 and less than half of the country is covered by lower Tx frequencies. However, when the block center is located in the other three sectors, the maximum Tx value is 1.8 and almost all of the country is covered with lower values. Even for the S4, all the country except a small area over the northeast part of the country had Tx values of 0%. The more eastward location of the block center has nearly the opposite effect on the Tn frequency distribution. When the blocking event was located further eastward, the maximum Tn value increases. The area covered by the lower Tn values decreases from S1 to S3. However, it increased again for S4. For S1, almost the entire country is covered by values lower than 0.5%. For S3, smaller areas of Turkey are covered by lower values. Briefly, the Tn frequency values increase when the blocking location approaches the country. This result is consistent with Sillmann et al. (2011). They concluded that atmospheric blocking events closer to the Europe continent have greater influences on minimum temperatures than blocking events occur in western Atlantic.

Third, Tx and Tn were examined when considering the BI. The Tx frequency change with respect to BI is not clear during the summer. The Tx frequency boundaries, as well as the areal coverage of values, are very similar for blockings with weak and moderate intensities. However, the impact of BI is clearer for Tn frequency across the country. The spatial coverage of the lower frequency values decreases with the increase in BI from weak to moderate. The maximum frequency of Tn reaches 5.0% during moderate intensities for summer. During the winter, the maximum Tx frequency decreases with the increased strength of BI. The maximum Tx frequency is almost 5% for weak blockings, while it is negligible for strong blocking events. The spatial coverage for lower Tx frequency values increased with increasing BI. For Tn frequency distribution, the spatial coverage of lower values is similar to that of Tx. The spatial coverage of lower Tn values increased with an increase in BI. The maximum Tn frequency decreased for moderate block intensities with respect to weak events and then increased for strong BI reaching 12.5%.

Then, the effects of the block size were investigated for Tx and Tn for the summer season. The block size has a different impact on Tx and Tn. An increase in block size decreases the maximum frequency of Tx values and increased in the area covered by the lower values. However, increasing block size increases the maximum Tn values without a precise influence on the area covered by the lower values. The observed distribution of Tn during large blocking events is opposite to that for small events, and this is the noteworthy result from this section. During the winter, the maximum Tx frequency is around 3.3% and almost half of the country is covered by the lower Tx frequency values for small-sized blocks. When the block size is moderate, the maximum Tx frequency reduces to 1.39% and the covered area increases. For the large events, the decrease in Tx frequency continues and reaches as low as 0.96% although the area coverage remains the same. For the Tn frequency, the maximum value increases in the S2 when compared to the S1, but it covers a smaller area. For the large events, it decreases to 2.2%. The area covered by the lower Tn frequency values decreases with the increase in block size.

Lastly, the impact of the block duration was analyzed. For the summer season, the block duration has an increasing effect on maximum Tx frequencies and decreasing effect on the spatial coverage of lower Tx values. The spatial coverage of lower Tn frequencies is minimum during short-lived events and maximum for moderate-duration events. The maximum Tn frequency value is greatest during short-duration events and smallest during moderate-duration events. During the winter season, the block duration has also the same effect as intensity. The maximum Tx frequency decreases, and the area covered by the lower Tx values increases with the increase in block duration. On the other hand, block duration has an enhancing effect on Tn frequency values. The area covered by the lower Tn frequency values decreases, and the maximum Tn values increase with the block duration such that there is almost no area with the lower Tn values during moderate and large blocking events. Long-lasting blocking events produce stronger cold advection as mentioned by Efe et al. (2020) and Sillmann et al. (2011).

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