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Seasonality of storm frequency in Türkiye

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Abstract. Continental windstorms are quite common in Türkiye, as well as in the Mediterranean basin. These storms have high frequency during hot and cold periods and transitional seasons. Türkiye is vulnerable to storms that are most effective in winter. When the distribution of the average number of stormy days during the year in Türkiye is analyzed by season, the season with the highest number of storms during the year is winter with a rate of 37%. The remaining seasons are spring (29%), fall (18%), and summer (16%). In the seasonal distribution of the storms that occur during the year, the winter season, which has the highest rate of occurrence, has an average of 4.9 days of storms. The spring and the autumn seasons have 3.8 and 2.4 stormy days, respectively. Storms have a high frequency during the cold season from October to May. Storms cause storm surges, floods, flash floods and roof blow-off disasters in the coastal zone of Türkiye, causing loss of life and property in the cold seasons.

Key words:
storm,
windstorm,
stormy day,
Türkiye

Introduction

Climate is the most important system that influences all the living and non-living environments on Earth. Climate and weather conditions have either direct or indirect effects on people's economic, social and cultural activities, as well as their welfare and health status. Although extreme weather events have obvious effects on people's feelings, weather conditions that are different from normal from time to time also cause loss of life and property. Changes in climate elements caused by global climate change or variability, which are frequently on the agenda, may lead to much more serious climatic radical changes in the long term. In this process, the increase in extreme weather events is remarkable.

One of the most important elements of the climate is wind. Storms can occur as a result of increased wind speed. A significant proportion of these storms can force the life of living things or cause socio-economic damage. Strong wind events can often develop with an effective mid-latitude cyclone. Strong winds are often associated with accompanying heavy rains. While strong winds generally cover weather conditions where the wind speed is less than 17.2 m/s, different definitions are used for storm events. Storms are generally referred to by definitions that include storm-developing weather conditions such as blizzard, dust storm, rainstorm, as they bring with them severe weather events such as hail, snow, rain, lightning and thunder. The storm definition adopted here is that used by the World Meteorological Organization (WMO) and the Turkish State Meteorological Service (TSMS) andinvolves windy weather conditions where the wind speed blows at a speed of 17.2 m/s (storm) and 20.8–24.4 m/s (strong storm) for at least ten minutes and above.

Windstorms are an important feature of the Mediterranean region's climate (Llasat 2009; Ulbrich et al. 2012). Wind speed shows the highest average values in winter compared to other seasons in the Mediterranean and Black Sea (Lionello et al. 2012; Rusu 2019; Bernardino et al. 2021). In winter, the north-easterly Bora wind predominates in the Adriatic and Aegean, while in summer and early autumn, pressure gradients between Eastern Europe and Anatolia lead to the development of Etesian winds that intensify further over the Aegean (Lascaratos 1992; Bergamasco and Gacic 1996; Poulos et al. 1997; Paklar et al. 2001). The Black Sea region wind speed generally decreases from west to east. North-easterly winds prevail in winter and north-westerly winds in summer (Bernardino et al. 2021).

In studies conducted on Europe, there is a general tendency towards a decrease in storm events towards calmer weather conditions after the 1990s (Alexanderson et al. 1998; Barring and Storch 2004; Smits et al. 2005; Matulla et al. 2008). While there was an increase in storm events in the western Black Sea until the 1980s and 1990s, storm events have been replaced by calmer weather conditions since the 2000s (Valchev et al. 2012). In their study, Çelik and Cengiz (2014) determined a decreasing tendency in annual average wind speeds in 72% of meteorological stations between 1975 and 2006. According to the areal evaluations, similar results are observed in most of Türkiye and the surrounding countries. It is predicted that the effect of subtropical high-pressure centers in the Mediterranean basin will be more effective in the coming years, and the eastward movement of the North-Atlantic-originated storms will shift towards more northern latitudes (Giorgi and Lionelli 2008). According to the global circulation models made for the year 2095, it is predicted that the storm activity will decrease greatly in Türkiye (Evans 2009).

Due to its geographical location, there are frequent storms in Turkey, which has coasts on the Mediterranean and Black Seas. Almost every storm event in Turkey causes structural damage to buildings and sometimes deaths. Air circulation (wind frequency and speed) changes in urban areas where strong winds and storms are, and these changes are especially concentrated around structures. According to studies conducted throughout Türkiye, these changes significantly alter bioclimatic conditions and generally environmental damage depending on wind speed and frequency in some urban areas (Türkoğlu et al. 2012). As a result of changes in wind speed and frequency, bioclimatic conditions are shaped differently in areas with natural materials and patterns (Türkoğlu et al. 2012).

The geographical location of a place and the effectiveness of pressure systems control the seasonal distribution and variability of weather events. With global climate change or variability, the effectiveness of micro- and macro-scale pressure systems also changes. A clear similarity is observed between the atmospheric activities and storms in the western half and western coasts of Türkiye. Between the years 2000 and 2010, of the strong winds that occurred in the Marmara region, 53.4% were in winter, 21.2% in spring and 22.2% in autumn (Deniz et al. 2013). From this point of view, it is clearly understood that the atmospheric oscillations determined by the pressure systems at the macro scale are also determinative in the seasonal distribution and variability of atmospheric activities. This study aimed to determine the seasonal distribution of storm frequency in Türkiye and to reveal the long-term seasonal variability of storm records. For this purpose, Kendall's tau test statistics were applied to storm data above 17.2 m/s. In addition, storm frequency data from all storm stages in the Beaufort wind force scale (8, 9, 10, 11, and 12) were used as storm data in this study.

Data and method

In the study, wind data from 207 meteorology stations throughout Türkiye were used that had been obtained from the Turkish State Meteorological Service (TSMS) (Fig. 1). Winds in the storm category were evaluated from daily average wind data. For this purpose, winds blowing more than 17.2 m/s were used as storm data. Although the length of the datasets differs according to the stations, they generally consist of 59 years of data covering the years 1960–2018. Standard SNHT and Buish and homogeneity tests were applied for the data used in the study. According to homogeneity tests, 21.7% of the stations are homogeneous and 78.3% are inhomogeneous. The inhomogeneity may be related to the increasing and decreasing tendencies in the storm data in general, as well as the increase in the building areas around the stations and the surface changes. These assessments were calculated seasonally and visualized with Arc-GIS software.

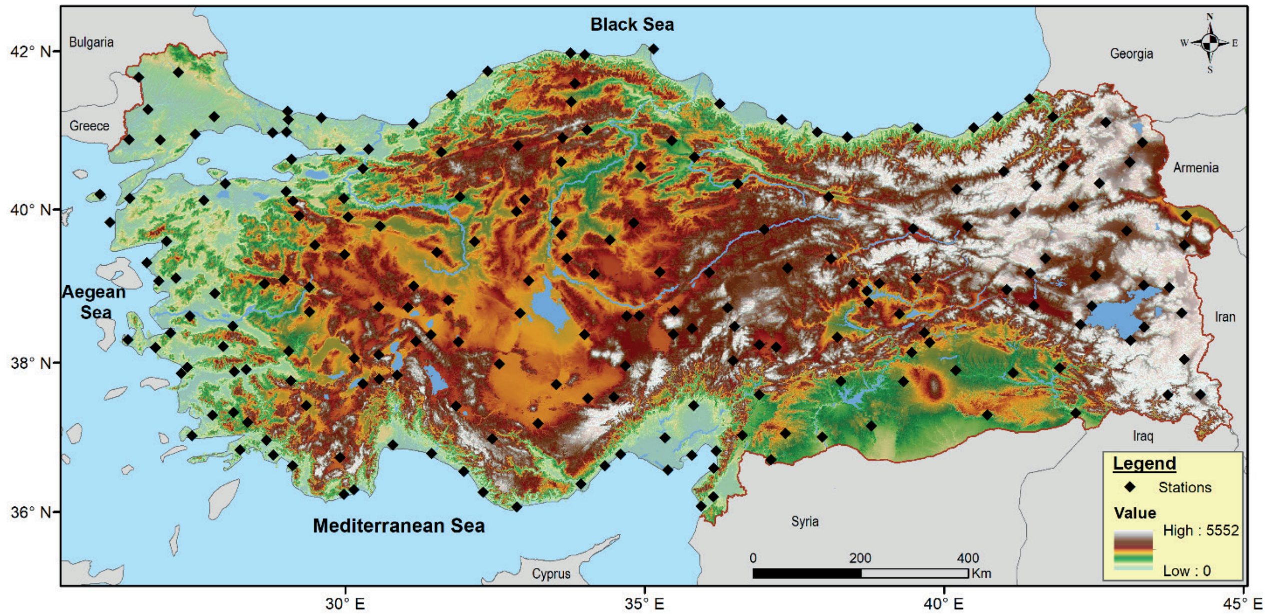

Fig. 1. Spatial distribution of the stations used in the study

Results

When the distribution of the average number of stormy days in Türkiye during the year is examined, the seasons with the most storms during the year are winter (37%), spring (29%) and autumn (18%) during the transition of hot and cold seasons. The storm rate (16%) in the summer season is quite low. Throughout Türkiye, the winter season is experienced as stormy on an average of 4.9 days. In the spring season, this figure is the second highest, with 3.8 stormy days. In autumn, there are 2.4 days of stormy weather. The pressure conditions, frontal systems, air masses, maritime–terrestrial features, orography, altitude steps, and natural and human water assets (lakes, ponds, dams) are effective in the seasonal variation in the occurrence rates of storms in Türkiye and the variation in storm densities between geographical regions.

Spatial characteristics of stormy days in winter

The increase in storm intensity in coastal areas and decrease in inland areas are due to the pressure conditions that affect Türkiye during the winter season. In this season, the interior parts of Türkiye become a cold air bowl, and high pressure settles in these terrestrial areas. Storm events are weak and variable on the high-pressure ridge in these areas. Due to the frequent passage of frontal depressions in these periods in coastal areas, the pressure weakens and the gradient between coastal areas and interior areas becomes stronger (Koçman 1993; Erinç 1996). Storm activity is strengthened at the transition of frontal depressions in coastal areas. The gradient between coastal areas and inland areas becomes stronger. Strong air currents develop from inland to coastal areas through breach areas where the topography is favorable. In this way, conditions suitable for storm formation are created. For example, depending on the determining effects of the topography, the prevailing storm direction at Silifke station in the Mediterranean Region occurs in the west-north-west and east-south-east directions (Fig. 2).

In the winter season, especially on the southern coasts, the storm direction is from the north in the areas where the mountain crevices and topography are suitable, and on the northern coasts the storms occur from the north. The direction of storms is mostly related to the direction of the effective fronts. But in many areas there are artefacts related to the direction of valleys that channel the winds. Especially in this period, the intensity of storms at Hopa station is related to the movement of south sector winds from the interior to the coast. Foehn winds, which are formed as a result of the adiabatic warming of the air, cause storms in these areas. Another important factor in the high intensity of storms on the western coasts is the strong activity of the westerly winds in winter. The high storm

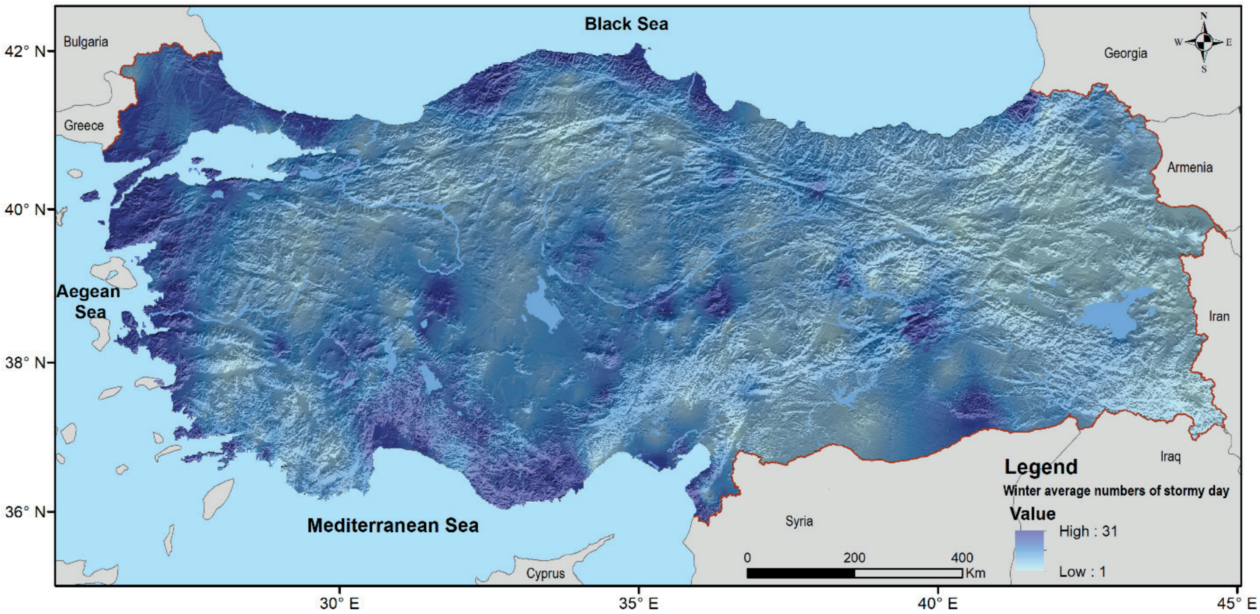

Fig. 2. Spatial distribution of the average numbers of stormy day in Türkiye during winter

intensity of the western, northern and north-western coasts is due to the fact that these areas are composed of low-altitude areas. Storm intensity is low in the areas other than the west, north-west and north because it can be said that the air masses and pressure systems, which will be effective because these areas are more high-lying than the coastal areas, undergo thermal and dynamic modifications and weaken their effects on storm activity.

It is observed that the intensity of storms is high in winter at some stations in terrestrial regions (Yunak, Pınarbaşı, Maden). The high storm intensity of these areas compared to the surrounding areas is due to the dam lakes, ponds and lakes that constitute water assets near Yunak, Pınarbaşı and Maden stations. During the winter season, when cold fronts are frequent, the water bodies in the vicinity of these areas create air that is warmer than that of their surroundings. The pressure gradient between the aquatic areas and their surroundings is strengthened and a relatively favorable environment for storms is created. Although the storms measured at the stations with the highest storm intensity in the winter season are mostly in the north sector, these stations are experienced in some years in the south sector storms. For example, in the winter season, the storm direction with the north sector and some periods with the south sector is remarkable, depending on the determining effect of the topography and the directions of the mid-latitude mobile depressions at stations such as Bozcaada, Çanakkale, Amasra, Kilyos and Samandağ, where the storm intensity is the highest.

Storms experienced in the winter season have a high frequency in the west-north-west coasts of Türkiye and the Black Sea coastline (especially the east of Rize), around Antalya-Silifke, the western part of the Nur Mountains, and around Elazig. Storm intensities in the interior and terrestrial areas are relatively lower than on the coasts.

Spatial characteristics of stormy days in spring

Spring is the season with the second-highest storm activity in the seasonal distribution of storms in Türkiye. With the spring months, it is observed that the intensity of the storm increases slightly from coastal areas to terrestrial areas. This season is the phase of gradual stabilization of the pressures affecting Türkiye (Koçman 1993; Erinç 1996). During this period, storm activity weakens in coastal areas and increases in continental areas due to the effect of continentality. In the spring, surface temperatures begin to increase, and significant local pressure differences occur for thermal reasons. At the same time, convective effects and continued activity of mid-latitude cyclones increase wind speeds. For thermal reasons, storm events in spring show a change from coastal areas to inland areas. Along with spring, storm intensity is observed at stations such as Kayseri Pınarbaşı, Konya Yunak, Sivas Suşehri in the interior, apart from Bozcaada, Amasra and Samandağ stations (Fig. 3). During this

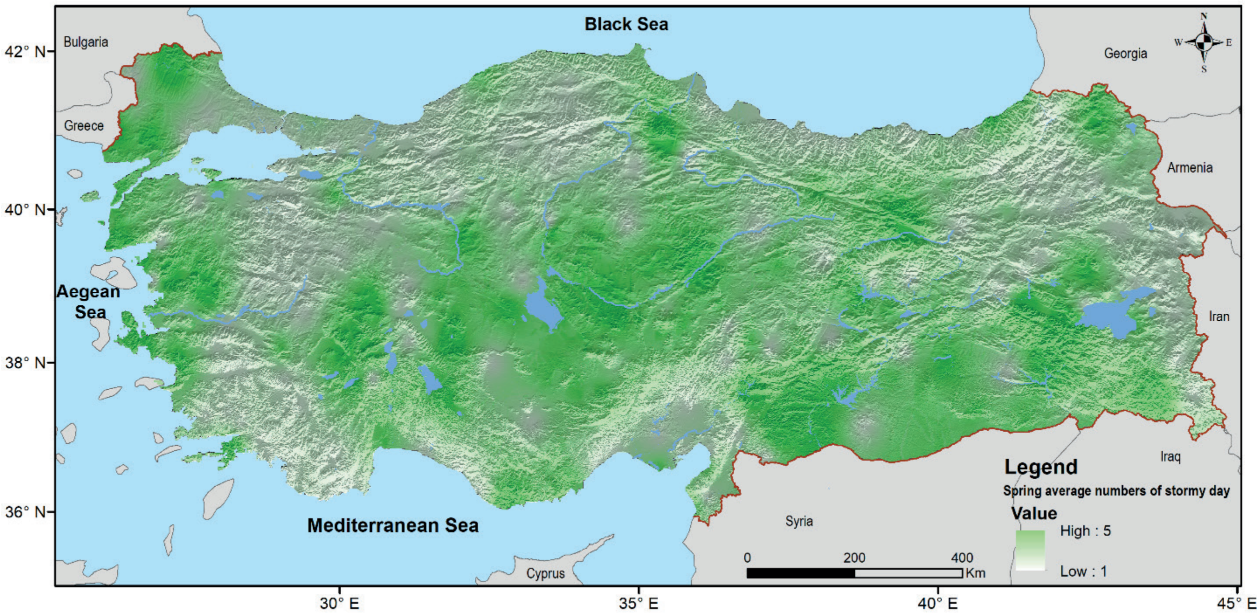

Fig. 3. Spatial distribution of the average numbers of stormy day in Türkiye during spring

period, storm frequencies are higher in continental areas where there are local differences, such as Suşehri, Ağın, Kayseri Pınarbaşı, Yunak. The presence of large and small water bodies (dams, ponds, lakes) in these areas causes local variation and increases storm development. These water bodies have an impact on the micro-scale pressure conditions in terrestrial areas. Therefore, these areas have higher storm frequencies due to differences in local pressure conditions.

Spatial characteristics of stormy days in summer

In the seasonal distribution of storms in Türkiye, summer is the season with the least storm activity (16%). It is observed that the intensity of storms in coastal areas clearly decreases in the summer season and intensifies in the continental areas in interior regions. The main reason for this is that hot-season pressure conditions prevail in the summer season. With the summer season, significant changes are experienced in the location of many pressure centers in the northern hemisphere. One of the most important changes takes place as monsoon circulation conditions begin to develop. With the settlement of the monsoon trough over Asia, low pressure develops in and around the Persian Gulf. The low-pressure center has a significant effect on the south-south-west part of Türkiye, and the increasing surface temperatures. The Azores High Pressure settling in the interior of Europe significantly shapes the wind and storm fields. Air currents start to flow from the Azores High Pressure to the low pressure around the Persian Gulf (Koçman 1993; Erinç 1996). The Aegean Sea basin, continental Greece, the southern Balkans and the high mountainous areas in Türkiye form a natural channel for the Etesian winds. The Etesian winds can be characterized as monsoon-type winds prevailing over a large area of the eastern Mediterranean, despite their large diurnal variations (Poupkou et al. 2011). The Etesian winds are strong in Çanakkale and its surroundings in this season (Fig. 4). In the evaluations made for the frequency and wind speed of the Etesians, reductions in the total number of Etesian days and monthly maximum wind speed were determined from June to September. The study for Greece (Poupkou et al. 2011) includes similar results with Türkiye's coastal belt.

Spatial characteristics of stormy days in autumn

Autumn is the season in which 18% of all storm events occur in the seasonal distribution of storms in Türkiye. In the autumn, storms generally intensify along the west-north-west coast and north-north-west coast of the country. In October, thermal high-pressure conditions begin to take

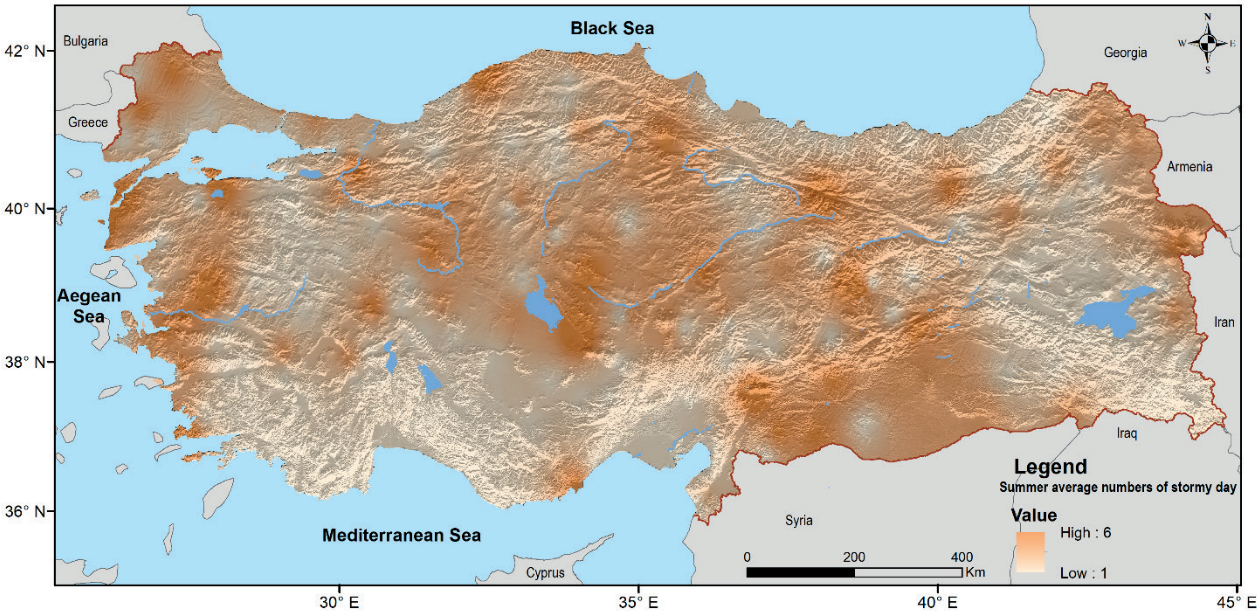

Fig. 4. Spatial distribution of the average numbers of stormy day in Türkiye during summer

place in central Europe and eastern Europe and the Caspian basin, which generally starts to cool. Air currents originating from the strengthening high-pressure areas enter Türkiye from the north, north-west and east (Koçman 1993; Erinç 1996). Storm activities migrate and intensify in these coastal areas. In Türkiye, storms start to increase on the northern coasts with this season, and storm frequency increases more towards the west in the winter season (Fig. 5).

In the autumn, storm activity continues with the effects of deep mid-latitude cyclones approaching Türkiye over the Mediterranean or the Balkans. Storm frequency increases especially in coastal and inland areas with orographic effects. The autumn storminess distribution shows spatial similarity with the winter season. Bozcaada, Çanakkale and Gökçeada stations in the north-western part of Türkiye and Black Sea coastal stations such as Amasra, İnebolu, Sinop and Hopa are also high in storminess due to increased mid-latitude cyclone frequencies (Fig. 5).

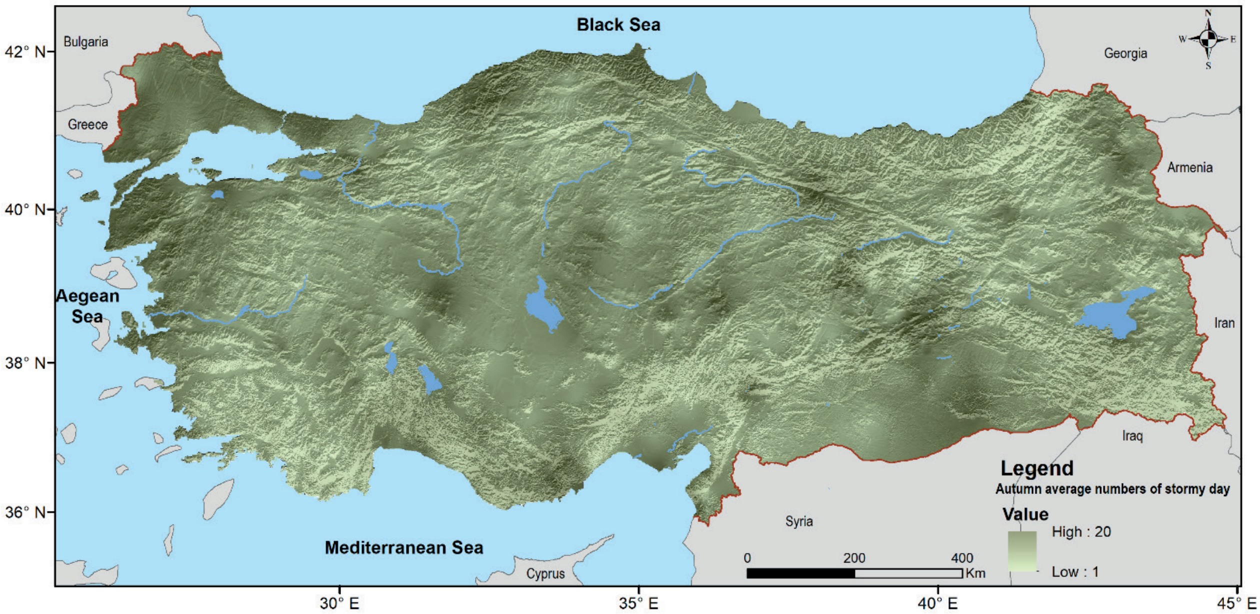

Fig. 5. Spatial distribution of the average numbers of stormy day in Türkiye during autumn

Discussion

The annual average number of stormy days in Türkiye is 11.4 days. This day rate varies in different geographical regions of Türkiye. Some stations with high annual average number of stormy days in Türkiye are Bozcaada (Çanakkale) with 62.3 days, Maden (Elazığ) 55.6 days, Amasra (Bartın) 42.7 days, Gökçeada (Çanakkale) 38.2 days, Sinop 38 days, Canakkale 37.9 days, Sarıyer (Istanbul) 34.1 days, Bodrum (Mugla) 31.8 days, Silifke (Mersin) 29 days, and Bandırma (Balıkesir) 26.8 days. The features shared by all areas with high storm intensity include topographic features suitable for storm formation and where winds can channel. For example, Çanakkale is one of the stations where the wind is channeled due to orographic effects. At the Çanakkale station, the storm intensity is high, and the dominant storm is in the north-north-west and south-south-east directions, which is the direction of the extension of the Dardanelles strait. The channeling of the wind by topography is quite evident at stations such as Suşehri, Silifke, Samandağ and Sarıyer. The Mediterranean basin is effective at topographically determining strong winds, such as the northerly mistral in south-eastern France (Jiang et al. 2003; Drobinski et al. 2005), the bora in the Balkans (Grisogano and Belusic 2009) and the Etesian in the northern Aegean. Winds develop in favorable atmospheric circulation features such as cyclones and upper-level troughs that develop in winter and spring in different basins of the Mediterranean. In the Mediterranean basin, cyclones also typically result from the interaction of synoptic-scale flows with mountains, limiting the flow in the lower troposphere and producing local and often strong winds (Raveh-Rubin and Wernli 2015; Lionello 2012). These characteristics in the Mediterranean basin are also valid for Türkiye. Türkiye's topographical features cause the wind to be channelized and blow strongly in many areas – for example, at stations such as Istanbul, Çanakkale, Silifke and Elazığ. At the same time, the number of stormy days is also high due to the cyclonic conditions affecting the Mediterranean basin during autumn, winter and spring.

Conclusion

In this article, the spatial distribution of storm seasonality in Turkey is examined. The main results of the study are summarized here: Storm activity in the interior of Turkey develops due to local, thermal and convective effects. The spatial distribution of storms is diversified by differences in surface characteristics (land area, water assets) and orographic effects. Depending on variations in atmospheric and local circulation characteristics, the areas of storm events vary between seasons. In addition, the changes in the pressure conditions that control the storm activity on the coasts, depending on the climate variability, closely affect the storm conditions in coastal areas. In the summer, storms are common in continental areas due to thermally induced pressure anomalies. Therefore, significant increase tendencies in terrestrial areas indicate that these changes occur slowly, and 2% of all stations with statistically significant increasing tendencies are examples of these changes. It is noteworthy that significant increasing tendencies are observed more in terrestrial areas, especially in the summer season when hot-period pressure conditions prevail, and significantly increasing tendencies away from the hot season towards the cold season decrease in terrestrial areas as well. However, terrestrial areas are more influenced by local thermal circulation systems. Significant upward trends in some terrestrial stations can be explained by changes in local thermal circulation conditions. During the temporal variability process, the frequency of storms in Türkiye is expected to increase in the summer seasons over land areas. In addition, increasing trends are expected in the number of stormy days due to local pressure differences in land areas.

In conclusion, this study was conducted to show the seasonal and spatial distribution of wind, which provides environmental and economic services to the Turkish region. Since the effects of climate change on wind are expected to be significant in the near future, the spatial distribution of storms over the period 1960–2018 was evaluated. Uncontrolled growth in urban areas and changes in surface characteristics may cause differences in the distribution of storms with the effects of climate change. There is a need to plan urban areas by taking into account the different wind and storm characteristics in line with changing climatic conditions.

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