Severe Hail Climatology of Turkey

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ABSTRACT

A climatology of severe hail (diameter equal to or exceeding approximately 1.5 cm) for Turkey is constructed from official severe weather reports from meteorological stations, newspaper archives, and Internet sources. The dataset consists of 1489 severe hail cases on 1107 severe hail days (days with at least one severe hail case) during 1925–2014. Severe hail was reported most often in the 1960s, followed by a decrease until the 2000s, and an ensuing increase in the past decade. Severe hail is most likely to occur in the afternoon and evening, and in spring and summer, particularly May and June. The geographical distribution implies that almost all of Turkey is prone to severe hailstorms. In 8.3% of the severe hail cases, very large hailstones (diameter equal to or exceeding approximately 4.5 cm) were observed.

1. Introduction

Insured losses owing to hail damage in Turkey accounted for over 60% of all weather-related insured losses during 2007–13 [$73 million (U.S. dollars) in 2013], according to the Turkish Agricultural Insurance Pool (TARSIM; TARSIM 2014; Fig. 1). The vast majority of the losses have been related to agriculture, which plays an important role in Turkey's economy (over $60 billion per year, or about 10% of the Turkish gross domestic product). A quarter of the working population (over 6 million) is engaged in the agricultural sector.

Turkey's worst hailstorms have been as devastating as severe hail events in the United States. For example, the 19 June 1932 hailstorm in İnebolu (near the northern coast of Turkey; see Fig. 2 for locations), reportedly contained hailstones as massive as 480 g, which broke windows and damaged roofs. The 15 June 1943 hailstorm that struck Akşehir and surrounding villages in the interior of Turkey produced a half-meter accumulation of hail, destroying nearly all crops within the hail swath. A hailstorm on 26 April 1963 in Diyarbakır (southeastern Turkey) resulted in dozens of injuries and damaged homes, and another hailstorm on 31 May 1972 in Tunceli (eastern Turkey) killed hundreds of sheep and goats. The 6 June 1975 hailstorm in Karabiga (northwestern Turkey) produced hailstones with diameters in excess of 5 cm, and killed hundreds of cattle, damaged buildings, and possibly killed two people (it is unclear whether the victims were killed by the hail or an accompanying flash flood).

A climatology of hail derived from the Turkish State Meteorological Service's (TSMS) database was included in a previous study by Ceylan (2007). Ceylan (2007) investigated the statistics of two different datasets: 17 661

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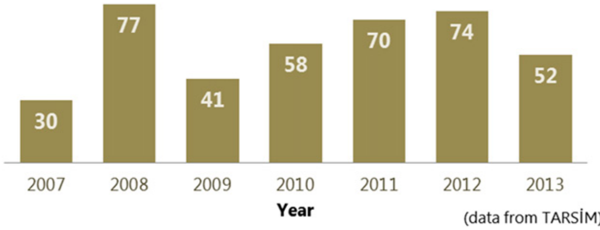

FIG. 1. Percentage of all insured agricultural losses due to hail damage in Turkey during 2007–13 (data from TARSİM).

hail observations from Turkish meteorological stations during 1967–2004 and 824 cases of *damaging* hail [referred to as ''hail disasters'' by Ceylan (2007)] during 1940–2004. With respect to the first dataset, there was an average of 425 hail occurrences per year, but with decreasing frequency between 1967 and 2004. In the damaging hail dataset, the frequency of occurrences increased during 1961–83, decreased during 1983–96, and increased once again during 1997–2004. The individual cases from that dataset are no longer available to us.

Owing to improvements in communications in recent years, it is now possible to obtain more information about local severe weather events than a decade ago. The Internet and widespread usage of smart phones have greatly increased reporting in Turkey. Furthermore, newspaper archives have been digitized, enabling much more efficient searches of historical events using keywords. The purpose of this study is to present an updated climatology of hail in Turkey that exploits the aforementioned improvements in severe weather documentation. In contrast to the prior work that focused on hail damage in Turkey (damage was often the result of significant accumulations of small hail), the present paper documents what we refer to as *severe hail*—hailstones with diameters equal to or larger than approximately 1.5 cm (the reason for the qualifier *approximately* will be explained in section 2). Documenting the occurrence of severe hail in Turkey is a necessary first step toward developing an understanding of the environments and processes conducive to its formation there. Forecasts of severe hail in Turkey cannot be improved without this understanding.

Definitions, data sources, and analysis methods are discussed in section 2. The findings from the climatology are presented in section 3. Conclusions are presented in section 4.

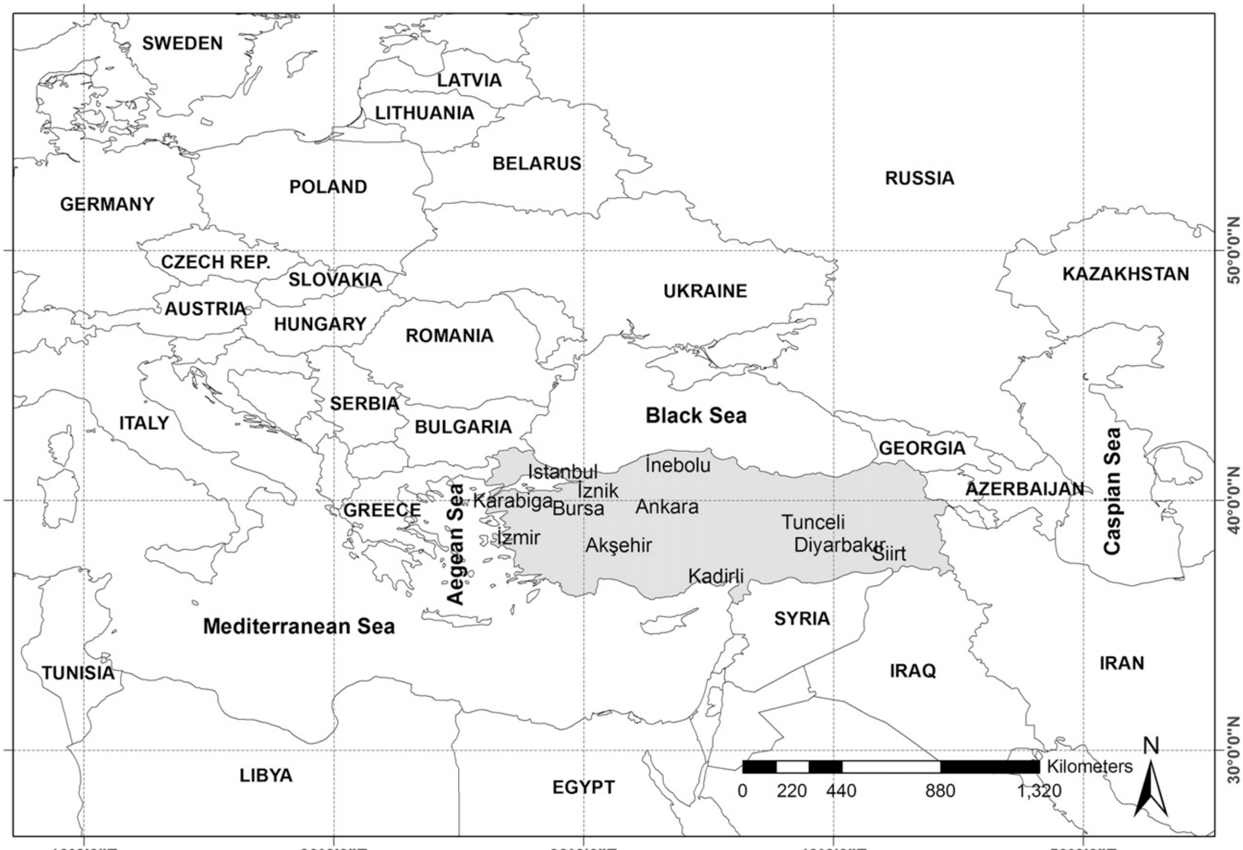

FIG. 2. Location of Turkey (gray shaded) and cities mentioned in the paper.

2. Data and methods

This section describes the definitions used in this study. It also describes the sources of data for the 1489 severe hail cases. In this study, the term ''case'' or ''event'' implies a specific severe hail occurrence on the ground, which is observed by one or more people, supposedly from a single storm cell (this will be defined in more detail in section 2c). The term ''report'' indicates the observation of one or more severe hail case. Although rare, one report may include more than one case, and one case may be reported more than once. The numbers given in the paper pertain to cases rather than reports.

a. Definitions of severe hail, very large hail, and large hail

Before developing a climatology of severe hail, careful consideration must be given to how severe hail will be defined. Hail severity usually is defined by hail diameter, even though not all of wide-ranging impacts of hailstorms are dependent on hailstone diameter only. A number of previous studies discussed this issue and mentioned other factors such as the wind speed during a hailstorm and the quantity of the hail on the ground (Webb et al. 2001, 2009; Sioutas et al. 2009). In addition to these, some studies have defined hail severity in terms of the kinetic energy of the hailstones (e.g., Vinet 2001; Eccel et al. 2012), which increases rapidly with hailstone diameter given that both mass and terminal fall speed increase with hailstone diameter. Another measure of severity can be the depth of the hail accumulation. For example, the European Severe Weather Database (ESWD; Brooks and Dotzek 2008; Dotzek et al. 2009) includes hailstones ''having a diameter (in the longest direction) of 2.0 cm or more and/or smaller hailstones that form a layer of 2.0 cm thickness or more on flat parts of the earth's surface.'' In the United States, the National Weather Service, since 2010, has defined severe hail to have a diameter equal to or exceeding 1 in. (about 2.5 cm) [prior to 2010, the threshold was a diameter of 0.75 in. (1.9 cm)]. Some prior studies have analyzed all hail regardless of severity. For example, Giaiotti et al. (2003) used data from a special hailpad network in the Friuli–Venezia–Giulia region of Italy, and Etkin and Brun (1999), Zhang et al. (2008), Suwala and Bednorz (2013), and Mezher et al. (2012) have documented hail statistics obtained from surface meteorological stations in Canada, China, central Europe, and Argentina, respectively.

Ideally, the present study would adopt a 2-cm-diameter threshold for severe hail to facilitate comparison to other hail climatologies in Europe. However, the available hail reports from Turkey rarely include quantitative size information. Instead, 98% (1465) of the 1489 severe hail cases compare hail sizes to familiar objects such as hazelnuts, chestnuts, olives, walnuts, and eggs, which obviously have a range of diameters. ''Hazelnut-sized hail'' represents the most commonly reported severe hail size (721 out of 1489 cases) in the Turkish records. Even though most hazelnut diameters fall short of 2 cm (hazelnut diameters are more typically about 1.5 cm), in the TSMS data, severe damage (especially to crops) is commonly reported with this size. Moreover, the reports also sometimes merely document average rather than maximum hailstone diameter. After considerable deliberation, hazelnut-sized hail is included in the climatology given the reported damage, uncertainty of maximum/average size during the events, and number of hail reports of that size. A walnut-sized hail threshold also was considered—''walnut-sized hail'' also is commonly referenced in Turkey (436 out of 1489 cases), and walnuts would logically be the next size increment up from hazelnuts—but was dismissed because walnuts tend to have diameters considerably larger than 2 cm. Such quantized reports of severe hail size is not an issue only for Turkey; Schaefer et al. (2004) show that more than 75% of large hail reports (defined as 0.75 in. before 2010) in the U.S. dataset describes hail size with three objects (dime/penny, quarter, and golf ball).

A subset of severe hail is classified in this study as *very large hail*, nominally equal to or larger than 4.5 cm in diameter. This category includes hail sizes compared to an egg (this is among the most common descriptions with 75 occasions), tangerine, fist, goose egg, and cigarette pack, among others. The determination of the 4.5-cm egg-sized threshold followed a similar approach to that of 1.5-cm hazelnut-sized threshold mentioned above. *Large hail* is classified as hail with diameters equal to or greater than 1.5 cm and less than or equal to 4.4 cm. Thus, the severe hail classification scheme presented in this paper is sum of the two classes: large hail and very large hail. Whenever the term *hail* is used in this article without qualifier, it is intended to mean all hail regardless of size (the sum of severe hail and nonsevere hail).

Table 1 summarizes the severity criteria used in the study. No matter how severe the reported hail *damage*, hail reports without any accompanying size description almost always are excluded from the climatology [the lone exceptions are reports of hailstones breaking windows and hailstones having ''sizes not seen before'' (5 of 1489 cases), which are placed in the 3.0–4.4-cm bin]. Moreover, as in any hail study, a reported hailstone diameter probably should be regarded as a typical or maximum observed hail diameter, though larger (and

TABLE 1. Hail classification scheme for the Turkish severe hail climatology.

Class	Nonsevere	Severe			
Size	Small	Large		Very large	
Diameter (d) (cm)	$d < 1.5$	$1.5 \leq d < 3.0$	$3.0 \leq d < 4.5$	$4.5 \leq d < 6.0$	$d \geq 6.0$
Sample keywords	Pea	Hazelnut, grape	Walnut, chestnut	Egg	Orange, fist

smaller) than observed hailstones might exist from a specific storm.

b. Origin of severe hail reports

Considering the relatively small spatial and temporal scale of hailstorms, any climatology based on observations will be limited by underreporting, especially in less-populated regions (e.g., the mountains in eastern Turkey). The higher number of reports around metropolitan areas such as Istanbul, Ankara, Izmir, and Bursa can be partially attributed to the high population density. The population of Turkey has risen from 13.6 million in 1927 to 76.7 million in 2013 (based on data from the Turkish Statistical Institute), with an impressive shift between rural and urban populations, as 24% of people in 1927 were living in urban areas and 76% were living in urban areas in 2010. Population density in the Istanbul province is 2725 people km^{-2} (slightly lower than Washington, D.C.), whereas it is only 11 people km^{-2} in the Tunceli province (similar to Nevada or Utah).

Underreporting may also be significant in areas without agriculture or other vulnerability to hail. According to Turkish Statistical Institute data, as of 2013, 26.5% of Turkey is arable/cultivated (in 2004, the figure was 23.1%). Reporting biases are further complicated by the fact that agricultural vulnerability to hail varies seasonally and as a function of crop type. Although there is no way to ensure that all severe weather occurrences have been captured, the climatology presented herein has been derived from hail reports obtained from a diverse mix of sources in order to capture as many events as possible, similar to the approach used by Tuovinen et al. (2009).

The most important source for the severe hail reports was the TSMS archive. The TSMS has maintained 459 different meteorological stations throughout Turkey since 1930, though fewer are operational at any given time (243 are in operation at the present time). In addition to making routine climatological observations, the TSMS meteorological stations report hazardous weather phenomena such as hail in their local areas. These reports include a written description (usually just a sentence or two, but occasionally longer entries are made) of the event and any injuries and property damage. Severe hail cases were obtained from a manual search of this archive from 1939 to 2012 by the first two authors. The search produced 1083 severe hail cases. Furthermore, the TSMS database contains hail frequency (all hail, not just severe hail) statistics by month during 1960–2013. These data were used to provide context for the locations of severe hail reports. Another 142 severe hail cases (during 2001–14) were obtained from the ESWD.

Digital archives of two national mainstream newspapers, *Cumhuriyet* and *Milliyet* were also combed for hail records. Currently, these are the only two national newspapers that maintain digitized archives. The keywords used for searching were ‘‘dolu yağdı’’ (hail fallen), ‘‘dolu yağışı’’ (hail precipitation), ‘‘büyüklüğünde dolu’’ (hail with size of), rather than only ‘‘dolu,’’ which is the literal translation of ‘‘hail’’ in Turkish (only searching for dolu was problematic because the word has popular alternative meanings such as ‘‘full’’). The *Cumhuriyet* archive, which is accessible via a paid membership, goes back as far as 1 January 1930 and was the source of 98 additional severe hail cases. A search of the *Milliyet* archive, which is freely accessible and contains articles from 3 May 1950 to 30 June 2004, yielded 20 more severe hail cases. Online records of *Hürriyet* and *Sabah*, two other national mainstream newspapers, were also searched. Although these searches were limited to roughly the last decade (the archives extend back to 8 July 1997 and 1 January 1997, respectively), these sources provided 40 and 12 new cases, respectively. Hardcopy archives of *Cumhuriyet* and another periodical, *Akşam*, also were searched manually starting in 1929, which is the first year the Latin alphabet was used in Turkey. This search added two additional severe hail cases to the climatology.

A search of additional Internet news websites in Turkey, with the Google.com.tr search engine, yielded 92 additional severe hail cases. Obviously, the credibility of Internet reports is often questionable. When available, satellite and radar images were used to verify the presence of a convective cloud or high reflectivity at the location of a severe hail report. It was also possible to investigate the reliability of the information via interactions with eyewitnesses using social media (Twitter and Facebook) in 17 cases. In some other cases, the municipality or local administration offices were called (since 2010) to verify the information found on the Internet. All these efforts yielded 1489 severe hail cases, of which 320 (21%) had multiple sources (cases mostly from recent years in which Internet reports abound).

c. Definitions of severe hail day and severe hail case

The term *severe hail day* is used in this study to refer to a day with at least one severe hail report, as in Tuovinen et al. (2009). When multiple severe hail reports are within 20 km of each other on a single day, they are merged into a single case. Some single severe hail cases might be the result of multiple storms, but the number of such instances is likely small. A storm with a long hail swath might be responsible for multiple severe hail cases if there are gaps in the severe hail reports along the storm's path that exceed 20 km. We suspect that a few such storms have been responsible for multiple severe hail cases in the climatology. Because the exact times of the severe hail reports are generally unknown (times are available for only 587 out of 1489 cases, or 39%), a time criterion like those used in previous studies could not be applied in this study. For example, hail studies in the United States (Schaefer et al. 2004) and Finland (Tuovinen et al. 2009) attributed a report to a new event if 15 min elapsed since the previous report, with 16-km and 20-km distance criteria, respectively.

3. Results

The climatology includes 1489 severe hail cases on 1107 severe hail days (days with at least one severe hail case) in Turkey during 1925–2014, of which 124 (8.3%) were classified as very large. These numbers correspond to 16.5 cases per year or 0.21 cases 10 000 $km^{-2}\,yr^{-1}$, and 12.3 days yr^{-1} or 0.17 days 10 000 $km^{-2}\,yr^{-1}$. The actual frequency must be higher given the large number of hail damage reports without size information and other severe hail events that may not have been reported at all. However, the annual average over the last 5 years of the dataset (2009–13), which may be more representative of the true frequency given the much greater availability of Internet reports, is 42 cases, or 0.54 cases 10 000 $km^{-2}\,yr^{-1}$, and 29 days, or 0.37 days 10 000 $km^{-2}\,yr^{-1}$.

a. Severe hail cases by year

Between 0 and 74 severe hail cases per year were documented during 1925–2014 (Fig. 3). Severe hail cases were most numerous in the 1960s, during which every year had at least 29 severe hail events (74 severe hail cases were reported in 1963). The 1970s and 1980s generally featured a decline in cases to pre-1960s levels. Curiously, a similar trend in the long-term precipitation records of Turkey exists, as they also show a peak in the 1960s and decrease afterward (Türkeş 1996; Toros 2012). Furthermore, lightning fatalities and injuries also increased in the 1960s in the country (Tilev-Tanriover et al. 2015). Although the underlying reasons for more frequent severe hail environments are not yet known, the track of extratropical cyclones might play a role. A shift of the North Atlantic jet stream's latitude in spring from about 45°N (during roughly 1960–80) to about 48°N (during roughly 1980–2000), with 1 $m\,s^{-1}$ faster speeds in the 1960s on average (Woollings et al. 2014), may be related to the precipitation and severe hail frequency trends. Since 2005, there has been an increase in the frequency of severe hail reports. From 2005 to 2013, the annual number of severe hail cases has increased from 17 to 43, and the annual number of severe hail days has increased from 12 to 32. Though we cannot rule out that meteorological factors partly contributed to the recent increase in the frequency of the cases, the trends likely also have been heavily influenced by changes in the availability of hail reports. For example, the availability of cases has greatly increased in the last decade owing to the Internet; 249 of 301 cases (83%) during 2004–13 originate from online sources (search engines, social media, newspaper archives, and the ESWD), whereas there are none before 1998.

The trend in severe hail days roughly follows that of the severe hail cases, with a correlation coefficient of 0.97 (Fig. 3a). However, days with more than one case increase in peak periods (e.g., during the 1960s and 2010s), which can be attributed to regional outbreaks or wider sources of information (especially for the recent years). The leading year is 1963 with 36 severe hail days, followed by 1965 and 1972 (34 severe hail days occurred in both of these years).

The trend in the frequency of very large hail cases compared to large hail cases over the period of the climatology (Fig. 3b) indicates a possible underreporting of severe hail before 1960. Though the frequency of very large hail is roughly steady throughout the climatology, the frequency of large hail is lower prior to roughly 1960 (we might naively expect that very large hail is unlikely to be unreported owing to its likelihood of having an impact). A similar argument has been made for the underreporting of F0/EF0 tornadoes (the F and EF ratings refer to the Fujita and enhanced Fujita scales, respectively), in that the number of tornadoes rated F1/EF1 or higher has exhibited little upward trend since the 1950s, whereas the number of F0/EF0 tornadoes has dramatically risen (Kelly et al. 1978; Feuerstein et al. 2005; Verbout et al. 2006). The peak year is 1963 with 6 very large hail cases; 55 (62%) of the years in the climatology have very large hail cases.

b. Hail size distribution

The frequency of occurrence of many rare events, such as tornadoes, extreme precipitation, and severe

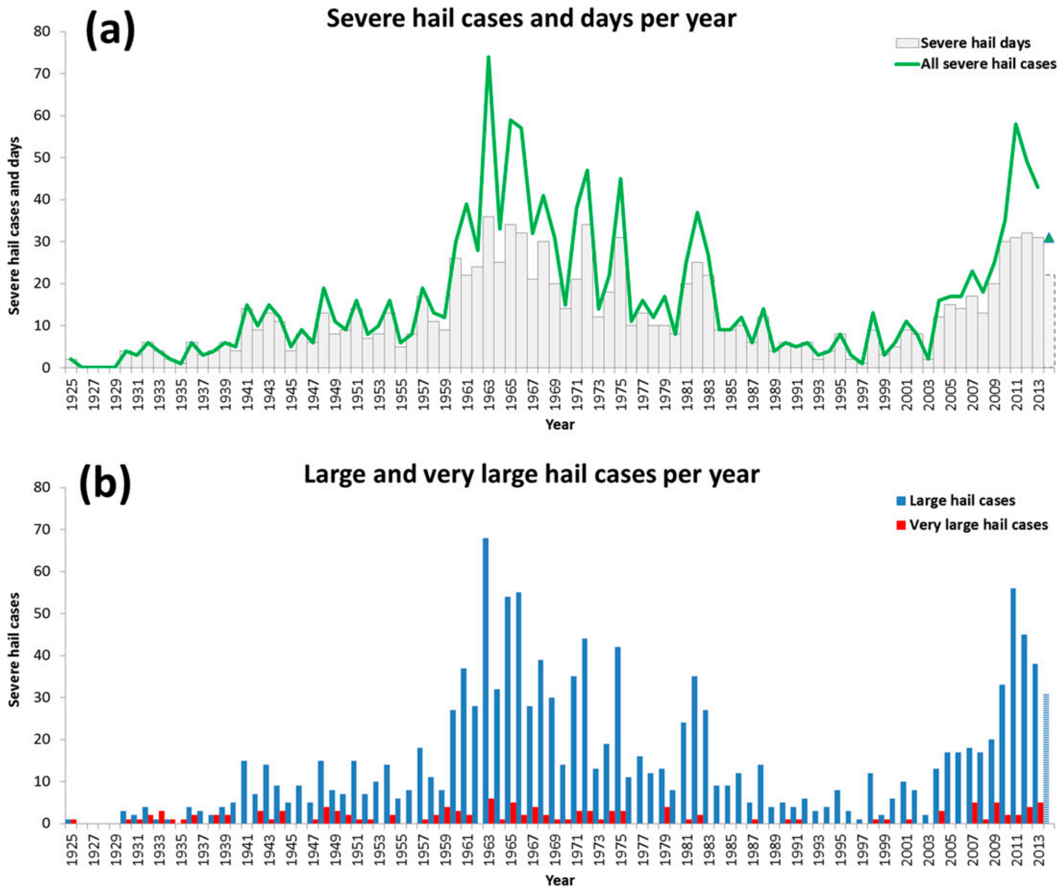

FIG. 3. (a) Severe hail cases and days and (b) large and very large hail cases in Turkey per year, 1925–2014 (the 2014 data are through 27 May).

winds, are known to approximately follow a log–linear decline with increasing intensity (Brooks and Doswell 2001; Brooks and Stensrud 2000). Following the approach described by Brooks and Doswell (2001) for tornadoes, the percentages of hail sizes are plotted on a log–linear plot (Fig. 4). The near-constant slope of the line in Fig. 4 indicates that the distribution of hail sizes equal to or exceeding 3 cm is not biased by size. The slightly smaller slope for the smallest hail sizes likely indicates an underreporting bias.

Of the severe hail cases in Turkey, 55% (821 cases) involve hailstone diameters smaller than 3.0 cm, and 36% (542 cases) are associated with hailstone diameters between 3.0 and 4.4 cm, inclusive (Fig. 4). There are 24 very large hail cases involving hailstone diameters equal to or larger than 6.0 cm (1.6% of all severe hail cases). The ratio of very large hail to severe hail in Turkey (defined as 4.5 cm or larger and 1.5 cm or larger, respectively) is 0.083, comparable to 0.082 for the United States (with 2.00 in and 0.75 in thresholds) as suggested by Schaefer et al. (2004), and far lower than Finland's 0.36 [5 cm or larger hail cases within 2 cm or larger hail cases; Tuovinen et al. (2009)].

The largest hailstone in Turkey is not exactly known owing to the rarity of objective size information in the hail reports. However, some extreme cases have been reported. These include a hailstone in Kadirli on 3 November 1936 estimated to weigh somewhere

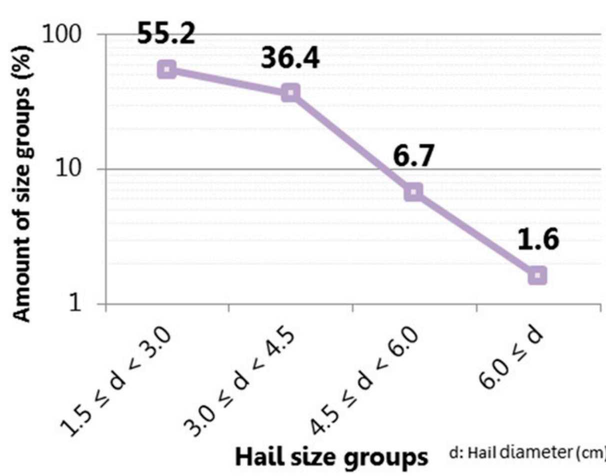

FIG. 4. Size distribution of severe hail cases in Turkey.

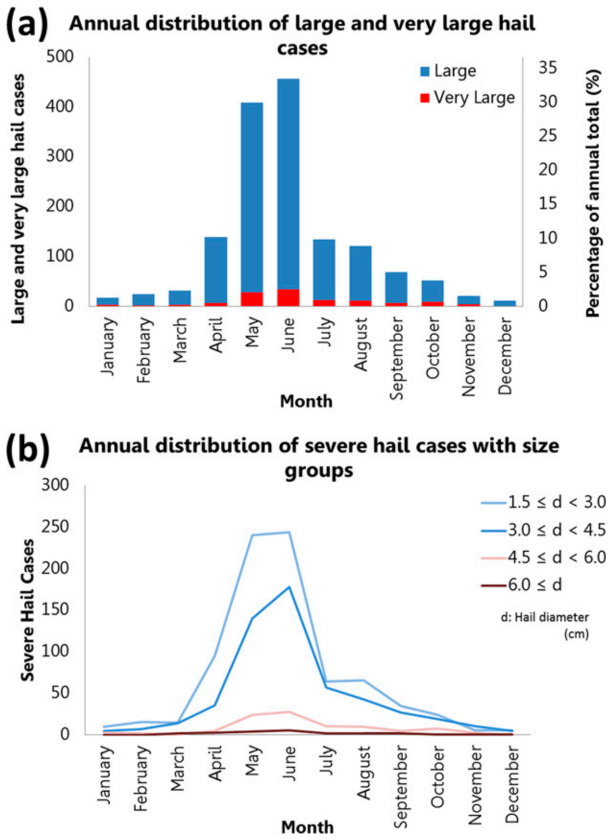

FIG. 5. Annual distribution of (a) large and very large hail cases and (b) size groups for severe hail cases in Turkey.

between 300 and 1000 g, a 750-g hailstone in İznik on 1 July 1947, and roughly a half dozen other reports of hailstones exceeding 400 g since the 1930s.

c. *Annual cycle and geographical distribution*

Severe hail in Turkey is most frequent in spring and summer. June is the peak month, followed by May (Fig. 5), with 864 events (58% of all cases) being reported in these two months. Moreover, very large hail also is most frequent in June (34 events) and May (28 events), followed by July and August (13 and 12 events, respectively). Hailstones with diameters larger than 6 cm have the same peak months, with 6 occurrences in June and 4 in May. Severe hail is least likely in December. The peak season is comparable to other parts of southern Europe. For example, the peak season for severe hail is late May to early July for Bulgaria (Simeonov 1996), May–June for northern Greece (Sioutas et al. 2009), June for northeastern Italy (Giaiotti et al. 2003), May through September for France (Vinet 2001), and May through July for northern Spain (Sánchez et al. 1996). On the other hand, Cyprus experiences severe hail more frequently in December, compared to other months (Michaelides et al. 2008), which is consistent with our results for the southern coasts of Turkey (discussed below).

The geographical distribution of severe hail cases is relatively uniform in Turkey when compared to tornadoes (Kahraman and Markowski 2014), and roughly follows the distribution of thunderstorm days as well as lightning fatalities and injuries (Tilev-Tanriover et al. 2015). Severe hail has been reported in all of Turkey despite considerable topographic variability (Fig. 6). However, regional differences in severe hail occurrences, as well as hail frequency overall (i.e., nonsevere and severe hail), are evident in monthly distributions (Fig. 7). For example, in the winter, when hail frequency is a minimum nationwide, hail still poses a threat along the Mediterranean (southern) and Aegean (western) coasts, where the proximity to the relatively warm water presumably provides the instability required for hail. In March, the region of higher hail frequency begins expanding into the interior regions, and by April the inlands generally have a higher hail likelihood (especially severe hail) than the coastal regions, particularly

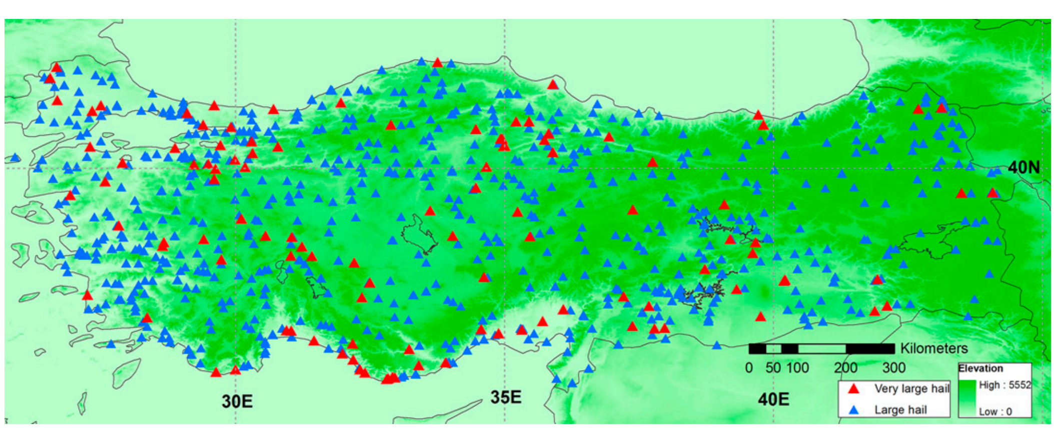

FIG. 6. Locations of large and very large hail cases in Turkey and topography.

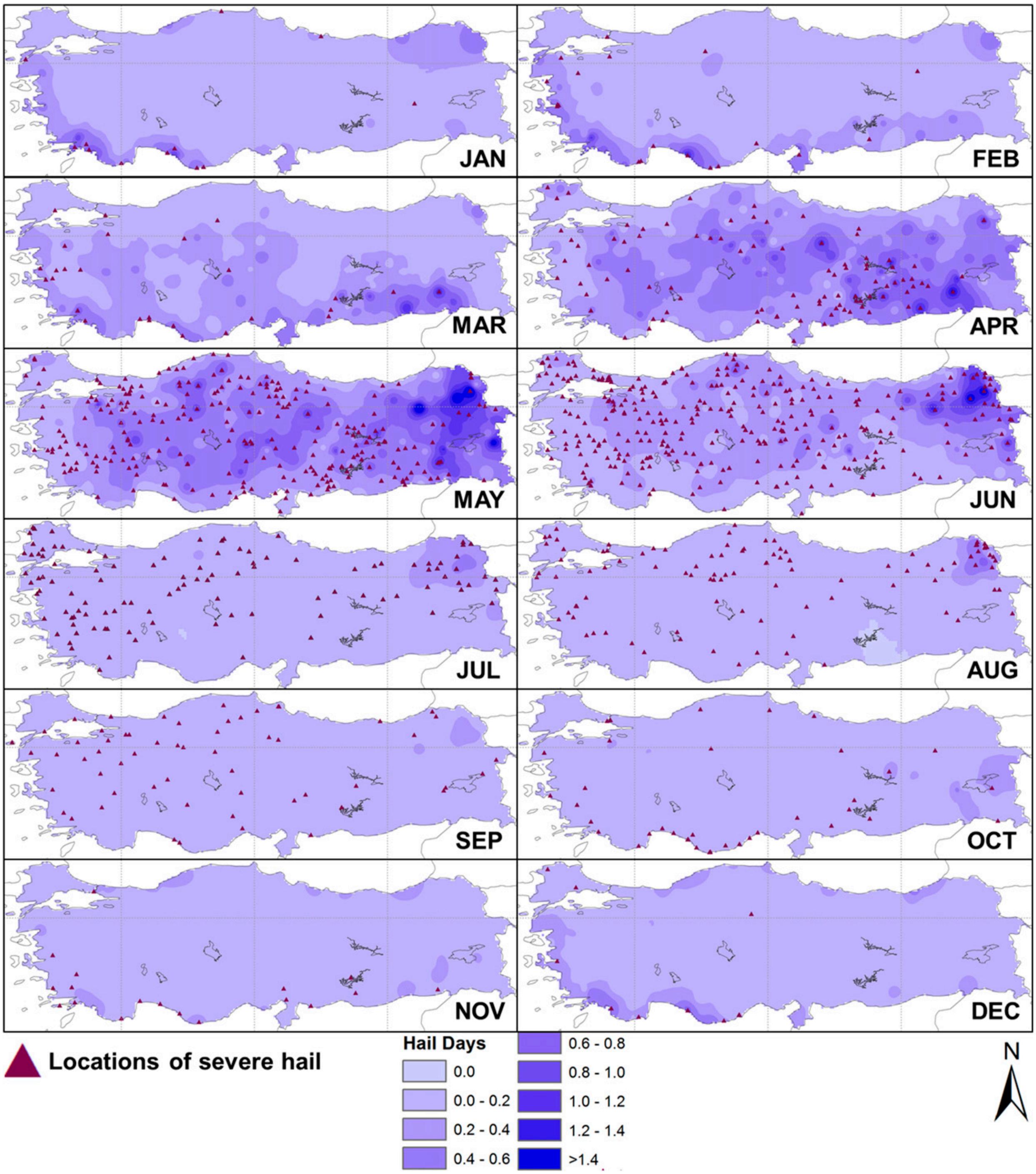

FIG. 7. Geographical distribution of all hail days (shaded) and locations of severe hail (red triangles) per month. All hail days data are from 277 stations of TSMS, 1960–2013. Data are bilinearly interpolated with an inverse distance weighting method (variable radius, second power), on a grid of 263 × 100 points.

southeastern Turkey, where there is a maximum in both severe hail cases and hail days (e.g., at the Siirt observing station, hail is observed an average of 1.5 days in April). In May and June, the peak season for severe hail, severe hail is most likely in interior Turkey, although the maximum in hail days lies in northeastern Turkey, where peak frequencies approach 2 hail days per month. As hail frequencies decline in late summer and fall

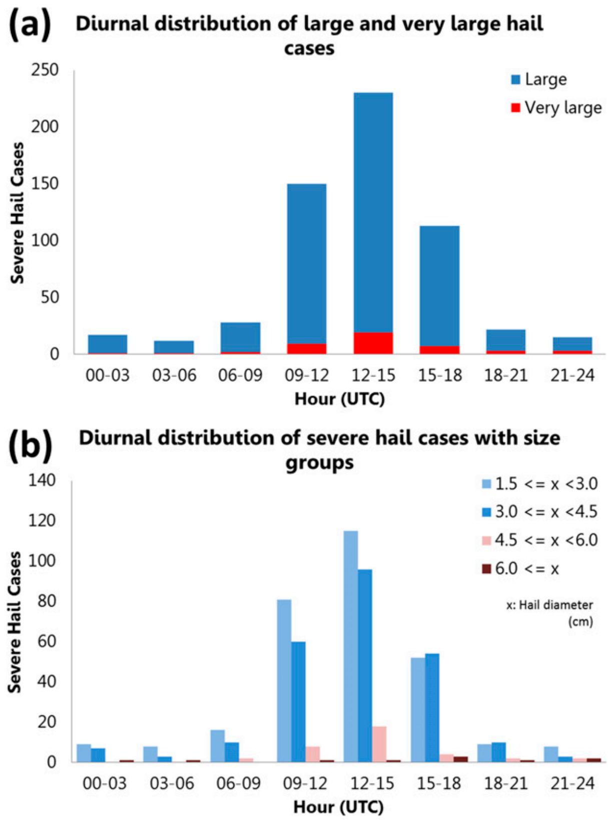

FIG. 8. Diurnal distribution of (a) large and very large hail cases and (b) size groups for severe hail cases in Turkey.

toward the winter minimum, hail probabilities decline most slowly in extreme northeastern Turkey.

d. *Diurnal cycle*

Severe hail is most frequently observed during 1200–1459 UTC (1400–1659 LST), with 230 cases, followed by 0900–1159 UTC (1100–1359 LST), with 150 cases (Fig. 8). The peak is similar for very large hail; 19 of 45 very large hail events occur between 1200 and 1459 UTC. Severe hail with a diameter of 3.0–4.4 cm more frequently occurs than 1.5–2.9-cm-diameter hail in evening hours (between 1500–1759 and 1800–2059 UTC). Of the cases with diameter of 6.0 cm or larger, the peak time interval is 1500–1759 UTC. However, severe hail cases have a nighttime minimum, presumably owing to a combination of less-frequent nighttime thunderstorms (Fig. 9) and underreporting.

4. Conclusions

Investigating the spatial and temporal distribution of severe hail is a prerequisite for understanding and ultimately predicting the environmental conditions that are favorable for severe hail. Turkey's severe hail climatology

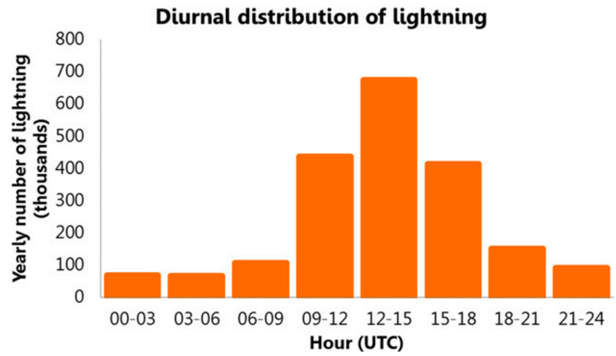

FIG. 9. Diurnal distribution of lightning in Turkey (yearly average with 1 Oct 2011–30 Sep 2013; data from Vaisala).

reveals that all parts of the country are vulnerable to severe hail ($\geq$1.5 cm), and it can occur in any season of the year. The largest hailstones exceed 5 cm in diameter and approach 1 kg in mass. Severe hail in Turkey is most likely in May and June, when severe hail is most likely in the interior of the country, especially in the east. Severe hail is least likely in the winter, though when it occurs in winter, it is most likely along the southern and western coasts. The afternoon and early evening hours are the most favorable time of the day for severe hail. The long-term variations in Turkish severe hail events (e.g., the 1960s maximum and early 2000s minimum) are worthy of future study.

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