



# Spatial and temporal variations in the incidence of dust events over Iran

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## Abstract

Dust events are natural hazards that frequently occur in many regions of Iran. The frequency of different categories of dust events over Iran during the period 1987–2016 and the first and second half of this period is analysed using visibility and the present weather data of 44 synoptic stations across Iran. These categories include dust in suspension, blowing dust, dust storm, severe dust storm and widespread dust. The frequency of dust events over Iran is calculated based on analysis of the three-hour-interval dataset of the synoptic stations and represented on a daily basis. Only one report in each day is enough to consider it as a dust event. Results indicated that the frequency of dust in suspension is extremely high over south-western and western Iran, while Zabol in eastern Iran has experienced the most frequent blowing dust and dust storm phenomena. In terms of seasonal variation of dust activity over different regions of Iran, the maximum and minimum frequency of dust events is observed in summer and winter, respectively. The frequency of dust phenomena during 1987–2001 is also compared against that during 2002–2016. It is found that the frequency of dust in suspension in most regions of Iran is significantly increased in the second period, particularly in western and south-western Iran. This implies that transport of dust towards western and south-western Iran has significantly increased in recent years. The frequency of blowing dust is also significantly increased in south-western Iran in 2002–2016 compared to that in 1987–2001, while changes in the frequency of blowing dust over Zabol in these two periods are negligible. The frequency of widespread dust is also analysed, and it is found that it only occurred over western and south-western Iran, with a much higher frequency during 2002–2016 than that of 1987–2001.

**Keywords** Dust in suspension · Blowing dust · Widespread dust · Frequency of dust events · Iran

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## 1 Introduction

The annual global dust emission ranges from 1000 to 3000 trillion grams (Tg), which contributes about half of the total tropospheric aerosols (Cakmur et al. 2006). Thus, globally, dust is the most abundant aerosol by mass in the atmosphere. Among different sources of dust aerosols across the globe, the Arabian Peninsula which is located within the Earth's 'dust belt' region (Prospero et al. 2002) is acting as a major source, ranking the second source of atmospheric dust on the global scale after North Africa (Tanaka and Chiba 2006). Indeed, based on a numerical investigation conducted by Tanaka and Chiba (2006), approximately 11.8% of the total global dust burden originates from the Arabian Peninsula. In particular, several years of war and water mismanagement in the Middle East region over the last few decades make this region more prone to dust events (Al-Ansari and Knutson 2011). Some recent studies have suggested that arid regions of Syria and Iraq also significantly contribute to the significant dust burden in and downwind of these regions (Alizadeh-Choobari et al. 2016; Azizi et al. 2012). Dust events in this region are generally associated with either the north-westerly Shamal winds in summer or low-pressure systems moving eastward from the Mediterranean in winter and early spring (Alizadeh-Choobari et al. 2016).

Recent studies have shown that the frequency of dust events has been increasing over some parts of the Middle East region in recent years, particularly over Iraq and western and south-western Iran (e.g. Shao et al. 2013; Alizadeh-Choobari et al. 2016). Indeed, inappropriate farming practices and mismanagement of water resources in Iran exacerbated the effects of an already dry climate. This combined with desertification of Iraq in recent years (IAU 2012) has contributed to the increase in the frequency of dust and sand storms across Iran in recent years. This highlights the importance of investigating changes in the frequency of dust events over Iran over the last few decades.

One of the first studies focusing on the frequency of dust events in the Middle East region was conducted by Middelton (1986) using ground-based observations. He found that the highest frequency of dust events occurs across a huge closed depression area located at borders between Iran, Pakistan and Afghanistan. This region comprises the Sistan Basin, the Registan Desert and north-western Balochistan. Contribution of the Sistan Basin as a major source of dust in eastern to south-eastern Iran and western Afghanistan was noted by Hickey and Goudie (2007). Another region identified by Middelton (1986) as a major source of dust in South-west Asia was the Makran Desert located along the coastal plain of the Oman Sea. Furman (2003) investigated temporal variation of dust activity in the Middle East region using dataset obtained from several synoptic stations of the region for the period 1973–1993. He found that the peak dust activity over Iran occurs in summer. Bolorani et al. (2014) found that the region between east of the Euphrates and west of the Tigris, western and south-western Iraq, eastern and south-eastern Saudi Arabia and south-eastern Iraq is the most important sources of dust in the Middle East. Also based on satellite imagery, dry regions of Iraq and Saudi Arabia are the main dust source for the south-west of Iran and the frequency of dust occurrence in the south-west is more than west regions of Iran (Azizi et al. 2012). It is well documented that human has had impact on making the Tigris–Euphrates basin a source of dust (e.g. Al-Ansari and Knutson 2011). More recently, Alizadeh-Choobari et al. (2016) used records of more than 300 synoptic stations across Iran during the period 1991–2010. They identified five regions of Iran where the frequency of dust events is relatively high. These regions include the Khuzestan Plain and the coastal plain of the Persian Gulf both in south-western Iran, western

Iran, Tabas and Sistan. They found that the peak activity of dust events over Iran occurs in summer. A rising trend in the frequency of dust events over south-western and western Iran during the period 1991–2010 was also noted by them.

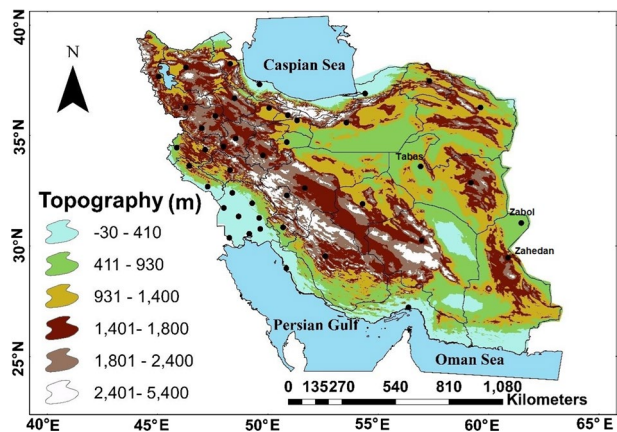
As Iran is located downwind of several sources of dust in Syria and Iraq, it is significantly influenced by dust aerosols originating from arid regions of these countries. In addition to these external sources of dust, several important internal sources of dust also significantly contribute to the high frequency of dust events over Iran. In particular, the Sistan Basin in eastern Iran acts as the most active source of dust in the interior of Iran (Middelton 1986; Alizadeh-Choobari et al. 2016). As discussed earlier, there is some evidence suggesting that the frequency of dust events over Iran has been increasing in recent years, which is primarily attributed to disturbance of the environment by human rather than natural climate variability (e.g. Alizadeh-Choobari et al. 2016). For example, during 1970s, Turkey's extensive dam and hydropower construction have considerably reduced water flows of Tigris and Euphrates into Iraq and Syria, causing the occurrence of more dust events over both Iraq and the downwind regions (Al-Ansari and Knutsson 2011).

In spite of its importance, the frequency of dust events over Iran and its changes in recent years are not well known. A recent study by Alizadeh-Choobari et al. (2016) tried to address this gap. However, they analysed the frequency of dust events over Iran during the period 1991–2010; thus, changes in the frequency of dust events in more recent years have remained unexplored. As such, the aim of this study is to investigate spatio-temporal variation in the frequency of dust events over Iran during the last 3 decades, i.e. 1987–2016.

## 2 Data and method

In this study, visibility and the present weather data of 44 synoptic stations across Iran for the period 1987–2016 at three-hour interval are obtained and analysed. Geographic locations of these stations are shown in Fig. 1. According to the World Meteorological Organization (WMO), dust events can be classified based on the report of visibility into four categories as described in Table 1 (Shao 2008; Shao et al. 2013). These categories include dust in suspension, blowing dust, dust storm and severe dust storm. Another category is also included in this study, which is called widespread dust and consists of a slight/moderate/severe dust storm that has been reported in at least three nearby synoptic stations.

**Fig. 1** Geographic locations of 44 synoptic stations across Iran whose data are used in this study. Topographical features of Iran are also overlapped. Locations of Zabol, Zahedan and Tabas are shown



**Table 1** Description of four different classes of dust events, which are defined in this study based on visibility. (Adopted from Goudie and Middleton 2006)

The present weather (code)	Horizontal visibility range	Description
Dust in suspension (06)	Less than 10 km	Suspended dust is observed at the station, but not raised by wind at or near the station at the time of observation
Blowing dust (07)	Between 1 and 10 km	Dust is raised by wind at or near the station at the time of observation
Dust storm (09, 30, 31 and 32)	Between 200 and 1000 m	Slight or moderate dust or sand storm
Severe dust storm (33, 34 and 35)	Less than 200 m	Severe dust or sand storm

The frequency of these dust events over Iran during 1987–2016 (hereafter referred to as the studied period) and the first (1981–2001) and second (2002–2016) half of this period is analysed. The frequency of dust events over Iran is calculated based on analysis of the three-hour-interval dataset of the synoptic stations across Iran and represented on a daily basis. Only one report in each day is enough to consider it as a dust event.

### 3 Results

#### 3.1 Frequency of dust phenomena during the period 1987–2016

Annual and seasonal means of the frequency of dust in suspension phenomenon over Iran averaged during the period 1987–2016 are shown in Fig. 2. It can be seen that the highest frequency of this phenomenon has widely occurred in south-western and western Iran, while Tabas in eastern Iran also shows relatively high frequency of this phenomenon.

Transported dust from Iraq, where the so-called Shamal wind blows, towards this region mostly contributes to the high frequency of dust in suspension over western and south-western Iran, as previously discussed by Alizadeh-Choobari et al. (2016). In terms of temporal variation of dust in suspension over different regions of Iran, the highest frequency of this phenomenon has occurred in summer, followed by spring. The least frequency of this phenomenon has occurred in winter. In winter, dust in suspension is only reported over parts of south-western Iran and this phenomenon is not reported in other regions of Iran.

The frequency of blowing dust phenomenon over some regions of Iran with relatively high activity is shown in Fig. 3. It can be seen that Zabol in eastern Iran has experienced the most frequent blowing dust phenomenon, such that on average annually more than 170 days of blowing dust is reported in this region. This is consistent with the results of Middleton (1986).

Interannual variation in the frequency of widespread dust storm during the period 1987–2016 is shown in Fig. 4. As can be seen, the highest frequency of widespread dust storm has occurred from 2008 to 2012. During the studied period, the year 2008 with 50 days of widespread dust storm ranks first, followed by the year 2009 with 35 days, although our analysis indicated that this phenomenon was more pervasive in 2009 and 2012 than 2008. On the contrary, no widespread dust storm was observed in 1990, 1995, 1997 and 1998. The absence of widespread dust over Iran in these years is consistent with the results of Alizadeh-Choobari et al. (2016) who found that the frequency of dust events is low in these years.

#### 3.2 Comparing the frequency of dust phenomena during two periods of 1987–2001 and 2002–2016

The annual frequency of dust in suspension phenomenon over Iran averaged during the first (1987–2001) and second (2002–2016) half of the studied period is shown in Fig. 5. It appears that in most regions of Iran, the frequency of dust in suspension is significantly increased in the second half of the studied period. The maximum frequency of dust in suspension in the first half of the studied period was recorded in only one of the stations in south-western Iran, while in the second half of the studied period, most stations in south-western and western Iran and one station in eastern Iran reported relatively high frequency of dust in suspension phenomenon. This implies that transport of dust towards western and

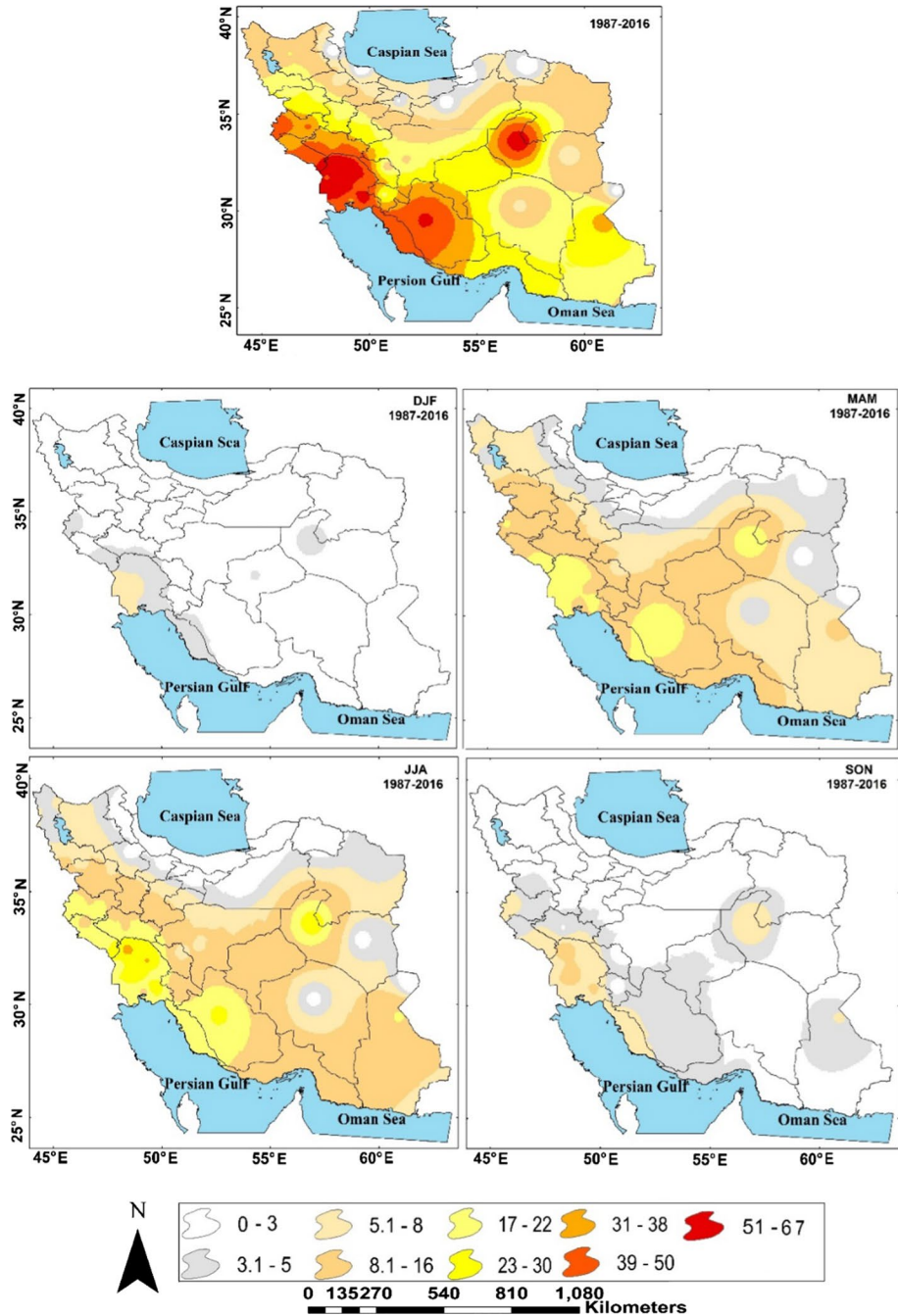
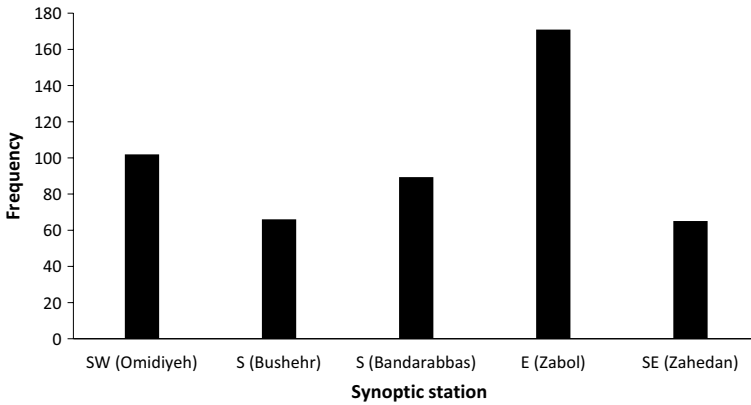
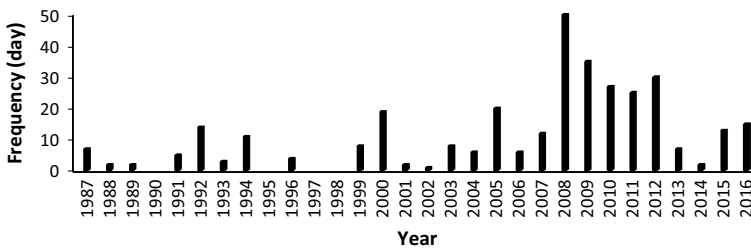


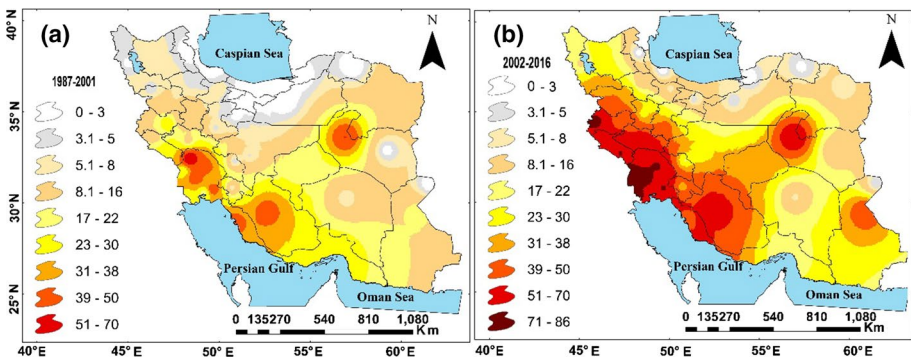
Fig. 2 Number of days with dust in suspension phenomenon over different regions of Iran on the annual and seasonal bases averaged during the period 1987–2016



**Fig. 3** The annual number of days with blowing dust over five different synoptic stations in Iran. Values are averaged during the period 1987–2016. SW, S, E and SE denote south-western, southern, eastern and south-eastern Iran, respectively



**Fig. 4** The annual number of widespread dust storm over western and south-western Iran during the period 1987–2016



**Fig. 5** Number of days with dust in suspension phenomenon over different regions of Iran on the annual basis averaged during the period 1987–2001 and 2002–2016

south-western Iran has significantly increased in recent years. On the contrary, the only station over which the frequency of dust in suspension is declined in the second half of the studied period is Bandar Abbas in southern Iran.

Seasonal frequency of dust in suspension over different regions of Iran during the first and second half of the studied period is also shown in Fig. 6. Similar to the annual frequency (Fig. 5), the frequency of dust in suspension is substantially increased in the second half of the studied period in all seasons of the year.

During both these periods, the highest frequency of dust in suspension in most regions of Iran occurred in summer, followed by lower frequencies in spring. In contrast, the lowest frequency of dust in suspension over different regions of Iran during both periods has occurred in winter.

The annual frequency of blowing dust in some synoptic stations with relatively high activity of dust during the first and second half of the studied period is shown in Fig. 7. It can be seen that the frequency of blowing dust in south-western Iran is significantly increased in the second half of the studied period, implying that emission of dust in south-western Iran has increased in recent years. On the other hand, a significant decrease in the frequency of blowing dust can be seen over Bushehr and Bandar Abbas in southern Iran. Among all the 44 stations studied here, Zabol experienced the highest frequency of blowing dust both in the first (177 days) and second (164 days) half of the studied period, with only a little decline in the second half of the studied period. As previously discussed, blowing dust is defined here as dust raised by wind at or near the station at the time of observation. Thus, it can be concluded that the highest frequency of dust emission across Iran over the last three decades has occurred in Zabol in eastern Iran. The frequency of blowing dust in these five synoptic stations during different months of the year is also analysed (not shown). Results indicated that the maximum frequency of blowing dust in south-western Iran is from May to July, while that in eastern to south-eastern Iran is from May to October, with the peak value in both regions occurred in July. On the other hand, the minimum frequency of blowing dust in south-western and eastern to south-eastern Iran occurred from November to February.

Among the 44 synoptic stations across Iran whose data are analysed in this study, the highest frequency of dust storm has been recorded at Zabol, particularly from June to September when the region is influenced by the wind of 120 days (Alizadeh Choobari et al. 2014). Our analysis also indicated that during the studied period, severe dust storms were only reported at Zabol in eastern and Zahedan in south-eastern Iran, particularly in June and July (not shown), such that some other stations only reported very limited number of severe dust storms over the last three decades.

Our analysis indicated that during the period 1987–2016, widespread dust only occurred over western and south-western Iran, with a much higher frequency during the second half of the studied period. Frequencies of this phenomenon over four stations in south-western Iran and four stations in western Iran in different months of the year during the first and second half of the studied period are shown in Fig. 8. It can be seen that from February to August, the frequency of widespread dust over western and south-western Iran is significantly increased during the second half of the studied period. We have also analysed the frequency of widespread dust in different months of the year and found that, overall, the highest frequency of this phenomenon over south-western and western Iran occurred in May and June during the first half of the studied period, while shifted to July during the second half.

Duration of dust activity is also an important factor that needs to be considered. Duration of widespread dust storms in those regions of Iran that are affected by this phenomenon during the period 1987 to 2016 is presented in Fig. 9. It can be seen that from 2008 to 2012, duration of widespread dust storm is relatively high, such that widespread dust with 6-day and 7-day durations was reported in 2008 and 2009, respectively.



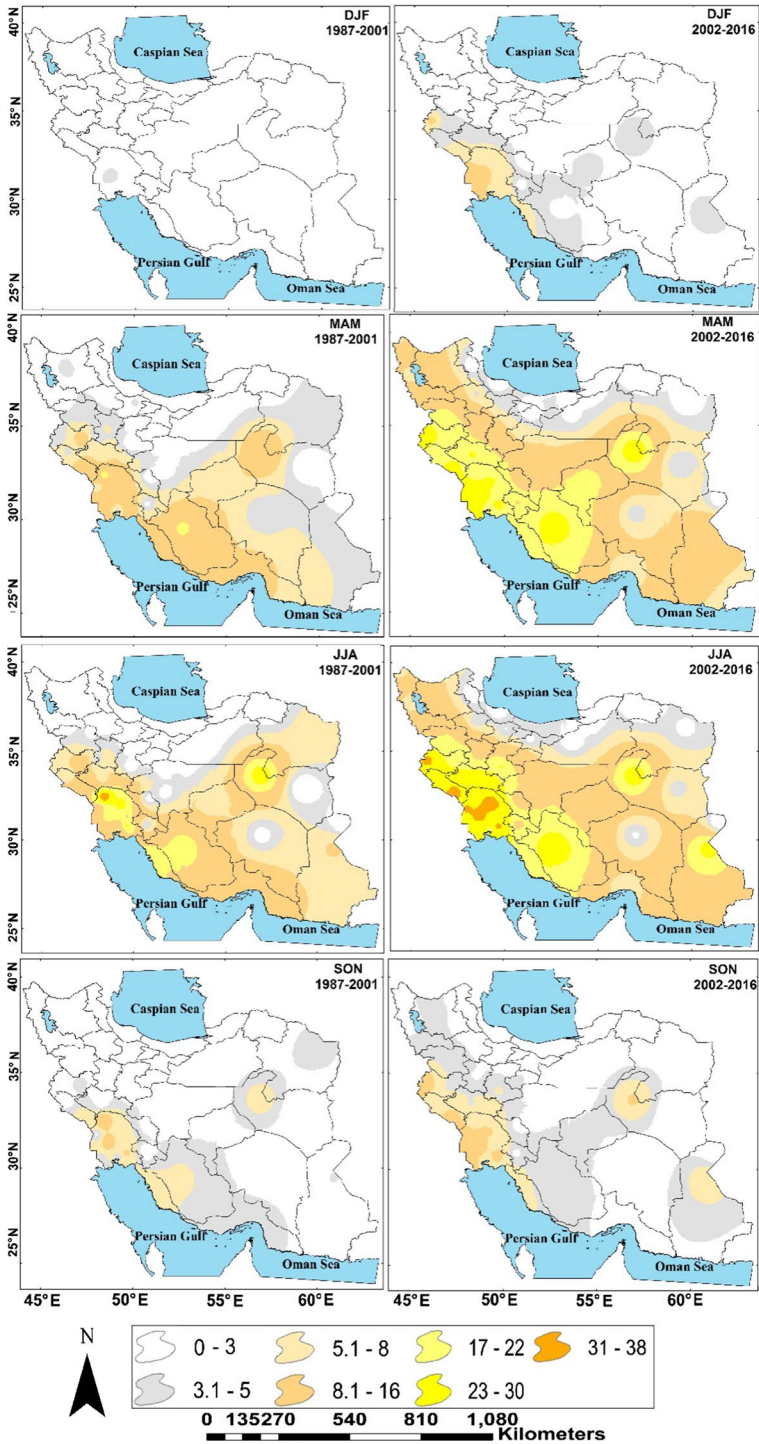
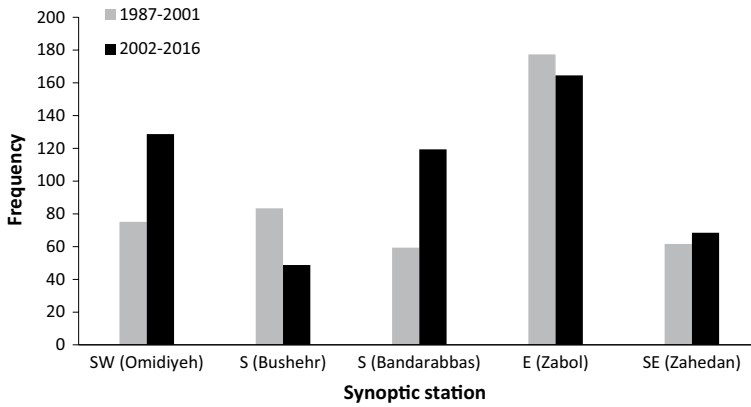
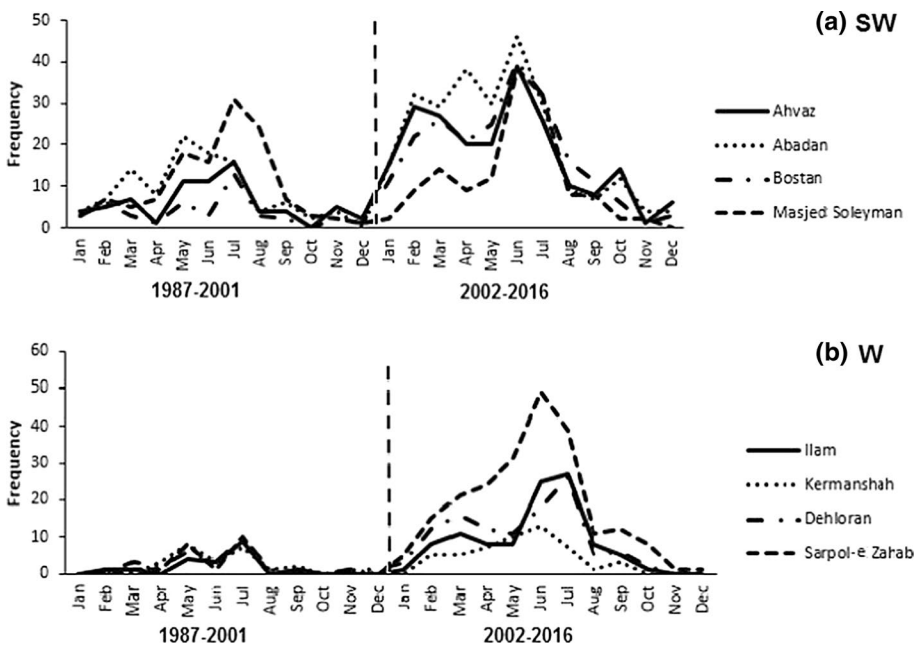


Fig. 6 The annual and seasonal number of days with dust in suspension phenomenon over different regions of Iran averaged during the period 1987–2001 and 2002–2016



**Fig. 7** The annual number of days with blowing dust over five different synoptic stations in Iran. Values are averaged during the period 1981–2001 and 2002–2016. SW, S, E and SE denote south-western, southern, eastern and south-eastern Iran, respectively



**Fig. 8** Monthly variation of the frequency of widespread dust in western and south-western Iran averaged during the periods 1987–2001 and 2002–2016

Figure 10 presents monthly variation in the duration of widespread dust for the first and second half of the studied period. It is clear that duration of widespread dust is significantly increased in the second half of the studied period. In particular, in the second half of the studied period, widespread dust with 6-day and 7-day duration is reported in June and July, respectively.

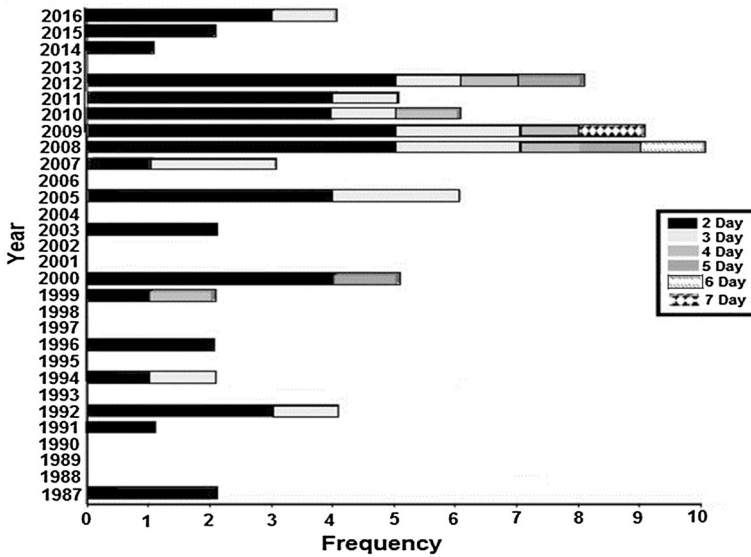


Fig. 9 Interannual variation in the duration of widespread dust storms over the regions that are affected by this phenomenon

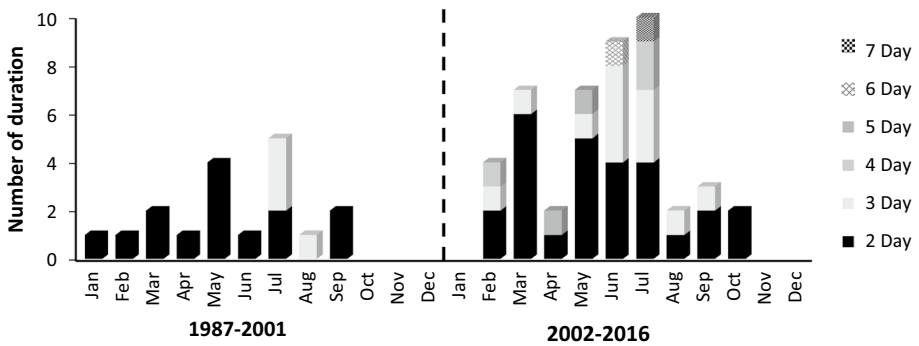


Fig. 10 Monthly variation in the duration of widespread dust storms over Iran averaged over the periods 1987–2001 and 2002–2016

### 4 Conclusion

The frequency of different categories of dust events over Iran during the period 1987–2016 and the first and second half of this period is analysed. These categories include dust in suspension, blowing dust, dust storm and severe dust storm. Another category is also included in this study, which is called widespread dust and consists of a slight/moderate/severe dust storm that has been reported in at least 3 nearby synoptic stations. To conduct the analysis, visibility and the present weather data were obtained from 44 synoptic stations across Iran during the studied period at three-hour interval. The frequency of dust events over Iran is calculated based on analysis of the

three-hour-interval dataset of the synoptic stations and represented on a daily basis. Only one report in each day is enough to consider it as a dust event.

Our results indicated that the frequency of dust in suspension is high over south-western and western Iran. According to the definition of dust in suspension provided in Table 1, this is an indicative that these regions are more significantly influenced by transported dust. Zabol in eastern Iran has experienced the most frequent blowing dust phenomenon. Based on the definition of blowing dust, this implies that the most important source of dust in the interior of Iran is located near Zabol. In terms of seasonal variation of dust activity over different regions of Iran, the maximum and minimum frequency of dust events over Iran is observed in summer and winter, respectively. Interannual variation in the frequency of widespread dust over Iran is also analysed. It is found that this phenomenon was highly active over western and south-western Iran from 2008 to 2012, while these regions are less affected by widespread dust in 1990, 1995, 1997 and 1998. Contributing factors to this significant interannual variation in the frequency of widespread dust need to be investigated.

The frequency of dust phenomena during 1987–2001 is compared against that during 2002–2016. It is found that the frequency of dust in suspension in most regions of Iran is significantly increased in the second period, particularly in western and south-western Iran. This implies that transport of dust towards western and south-western Iran has significantly increased in recent years. The frequency of blowing dust is also significantly increased in south-western Iran in 2002–2016 compared to that in 1987–2001, implying that emission of dust from this region is also increased in recent years. Nevertheless, a significant decrease in the frequency of blowing dust is observed over some regions in southern Iran during the 2002–2016, while the frequency of blowing dust over Zabol has not changed considerably in these two time periods. It is found that Zabol experienced the highest frequency of blowing dust and dust storm during the period 1987–2016, based on which, it can be concluded that the highest frequency of dust emission across Iran over the last three decades has occurred in Zabol. The frequency of widespread dust is also analysed, and it is found that it only occurred over western and south-western Iran during the studied period (1987–2016), with a much higher frequency during the second half of this period.

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