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The effect of wind direction on dust transfer toward the Persian Gulf

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ABSTRACT:

Introduction: Dust is a natural process in desert areas, which is caused by the effect of strong winds on the surface of the soil. The aim of this study is to investigate the conditions of the formation and expanding the dust storm formed in Iraq to the Khuzestan province in February, 2017.

Materials and methods: The synoptic analysis was conducted using meteorological parameters from ERA-interim and observation data from the Ahwaz station. In addition, the EUMETSAT image, the DREAM and the HYSPLIT model output were used.

Results: As the results show, regarding to the storm, dust in low- pressure area located over Iran is expanded toward the west associated with the tough 500 hPa . With the formation of the high-pressure area in Syria, a pressure gradient is formed in Iraq resulting the northwest wind with the wind speed of 28 knots s (14 m/s) in 925 hPa. These conditions have led to transport the dust from Iraq toward southwest of Iran. A jet stream is formed 12 h before entering the dust from Iraq to Iran, at 900 hPa. The HYSPLIT model predicts the particle's motion along the northwest winds, and is matched with the wind field in synoptic structure.

Conclusion: According to this study, the most important factors in dust transport to the Persian Gulf are geographic location of the low- and high-pressure area and the formed northwest winds in Iraq.

Introduction

Dust storms are one of the present problems in the west and southwest of Iran. The formation of dust and its transportation from sources to other adjacent areas bring harmful effects in various parts, including health and socio-economic domains and the climate change. As an atmospheric phenomenon, dust has also adverse effects on the environment and particularly endangers the health of individuals. Understanding the mechanism, origin and effects of dust storms plays a significant role in determining its control methods. In general, atmospheric phenomena creating dust have different synoptic, regional, local, and turbulence scales [1]. The transport trajectory of dust in East Asia and identified three different conditions for rising and transporting the dust [1]. Dust is divided into two modes in terms of vertical expansion. The low-level dust are below 700 hPa, and the free atmosphere dust are above 700 hPa and sometimes even up to 350 hPa. The as-

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cent and subsidence structure is different in these two types. The synoptic conditions studied during different stages in the trajectory of the particle showed that the stages of particle ascent and transportation by wind field and the subsidence below 700 hPa vary in different types of dust storm. Other effects, such as orographic structure, are important in creating upward motions and vertical transportation of dust. For each occurrence of a storm, various types of transport may occur and it depends on the position of dust source area and the vertical motion caused by the trough. The result showed that the transport conditions of dust depend on the location of dust source relative to the synoptic systems. In some cases, dust is formed near the fronts under cyclone conditions. If the dust source is in front of a high-level trough and the system experiences the temperature and vorticity advections, the condition is favorable for upward motion and can be transported to higher altitudes. In this situation with the ascending motion, the vertical transportation of dust is between 700 and 400 hPa in free atmosphere. In this type, the dust is transported to a farther distance, and the persistence of dust in the free atmosphere is relatively high. In another case, the dust source is located between a low pressure and a high pressure. In this case, if the particle ascends in a region close to the trough and is affected by subsidence motions, its horizontal displacement will be limited. In some cases, this phenomenon is formed near a high pressure under the anticyclone conditions. In this case, the dust source is located in the subsidence part after the trough was passed. In this case, the horizontal transportation is lower and they will not travel a long distance.

Due to the downward movement, the vertical transportation will be very limited and the particle will remain below 700 hPa level. In West Asia (Middle East), the systems generating the dust are divided into three types: front, convection and North [2]. The synoptic structure is an important factor in creating atmospheric circulation and transporting dust of foreign origin to Iran. In this regard, numerous studies have been conducted. Due to the difference in atmospheric conditions in the warm (first six months) and cold (second six months) seasons of the year, the effective systems for the formation and transportation of dust during the both periods are very different. The dust in Australian was associated with the high-level subsidence and the cold fronts of surface cyclones [3]. The synoptic characteristics governing the formation of dust storms in northeast Asia found the dust storm is always accompanied by a low pressure or cyclone system [4]. The dust system develops when a low-pressure system arrives to this area [4]. The amount of dust in the warm sector of cyclone reaches its maximum level. The storms have a dynamic structure in the cold season and are often of a frontal type. In the cold season, using the mean sea level pressure maps, 500 mb geopotential height, and wind field, it was observed that the migratory systems with western winds and polar jet stream led to the formation of dust in western Iran [5]. The synoptic patterns of dust storms for several storm surges during the cold season showed that the subsidence of middle level of the atmosphere and surface cyclones is affecting the transportation of dust from the deserts of Iraq, Syria and Jordan [6]. In the cold season of the year, the low-height center and western waves are formed on Europe and the Mediterranean Sea, from which the troughs are transported with cold weather to the Middle East. The occurrence of strong surface winds is the main cause of dust. The dust is formed in the event that the atmospheric forcing increases the wind speed and the wind speed can exceed the local threshold speed [7]. The formation of a significant horizontal pressure gradient in the transition zone between the low pressure and high pressure systems causes increases the wind speed, which in turn results in the development of low-level jet streams [8]. The low-level jet stream causes the horizontal transportation of the dust particles in a deep layer of atmosphere, and the presence of this jet prevents the transportation of dust to higher atmospheric layers [9]. The low-level winds are not able to transport particles up to a long time and distance, but transport the particles smaller than 100 µm for several days or weeks and several kilometers away from the formation place. The wind speed threshold for the dust formation is set at 6 m/s in the desert areas of northwest Asia [4]. The wind speed threshold for low levels is 5-13 m/s, and in some source areas, it reaches up to 20 m/s. The difference in wind speed depends on the erosion level of soil and surface materials. The location of LLJs with synoptic systems is mentioned in some studies. The synoptic analyses showed that strong surface winds along with the approaching of a cyclone or passing cold front lead to dust generation [1]. The downward mixing turbulence of momentum is due to the low-level jet streams. About 65 percent of the dust activity on the desert is caused by the break of night jet streams [10]. The release of dust throughout the year in the Bodele area in Chad is mainly due to low-level jet streams [11]. The low-level jet streams with the northern direction along the Iran-Afghanistan border are 300-500 m above the surface in July with the maximum monthly wind speed of 20 m/s in the middle of the night [12]. The study was focused on the role of low-level jet streams and result shows jet streams are observed from May to September at 850 hpa level and the maximum wind speed occurs between 18:00 and 00:00 (UTC) [13]. In the mentioned studies, the low-level jet stream in Sistan region, southeast Iran have been considered. The findings indicate that one of the effective factors in the dust is the low-level jet stream [14]. The results of the studies showed that in the atmospheric systems leading to the production and transportation of dust in the region, a jet stream is formed with northwest and north direction in the central and eastern lowlands of Iraq. The role of jet stream in the development of dust storms was studied, and the results show that the subtropical jet stream ascends the air of the Saudi plateau to the high latitudes and the polar jet stream transports the air of high latitudes to the south latitudes, and their interactions are one of the factors that create the low-level jet stream [14].

One of the most important factors is the origin of storm dust formation. The exact recognition of the dust origin is of particular importance, because the type and size of the particle have a special effect on the type and intensity of pollution and darkness of the atmosphere as well as the human health. In the study of winter and spring dusts in the west of Iran concluded that they originated from the storms in the north and north-east Africa or Saudi Arabia, Iraq and Syria. The main source and origin of dust in the Khuzestan province is the dried lakes and the alluvial vegetation-free regions in southern Iraq, the al-Nafood and Dehnaa deserts in northern Saudi Arabia, and the al-Sham desert in southeastern Syria [15]. Also introduced two main centers of the western region of Baghdad and Mosul to Bahrulmalah and Hoor al-Azim based on satellite images, which the former is a foreign source and the latter is a domestic one [7]. The HYSPLIT model is an atmospheric model by which the source of dust can be determined. Several studies have been conducted in this regard. Using the HYSPLIT model, identified the main sources of dust in southwestern Iran as the northern Iraq, eastern Syria, and northern Saudi Arabia [16]. In most studies using the HYSPLIT model, in general, the range between northern Iraq, eastern Syria and northern Saudi Arabia has been determined as the dust source in western Iran [16]. The dust trajectory using the HYSPLIT model and showed that the lake is able to affect thousands of kilometers of the Asia continent under the atmospheric circulation over a short period of time [17]. By using the HYSPLIT reviewed the 2008 dust storms and identified North Africa, Middle East, Mongolia and northern China with a high frequency of dust events [17].

Materials and methods

In this study, dust storm was selected for the period February 17-20, 2017 as a case study. This storm was formed in Iraq and moved towards the southwest Iran and covered the Khuzestan province and parts of the Persian Gulf. The studied area and stations of Abadan and Ahwaz in southwest of Iran (Khuzestan province) and Bushehr and Kharg (Bushehr and Persian Gulf) were selected as control stations and two points in latitude 32° on Iraq representative of Iraq deserts are shown in Fig 1.

In order to investigate this dust storm, in addition to horizontal observation data at the control stations and the DREAM outputs and the images obtained from the EUMETSAT satellite, the study of storm trajectory was reviewed through the HYSPLIT model. The observation data was collected for Abadan, Ahwaz and Kharg Island stations from the National Meteorological Organization. The geographic position data of the stations are shown in Table 1.

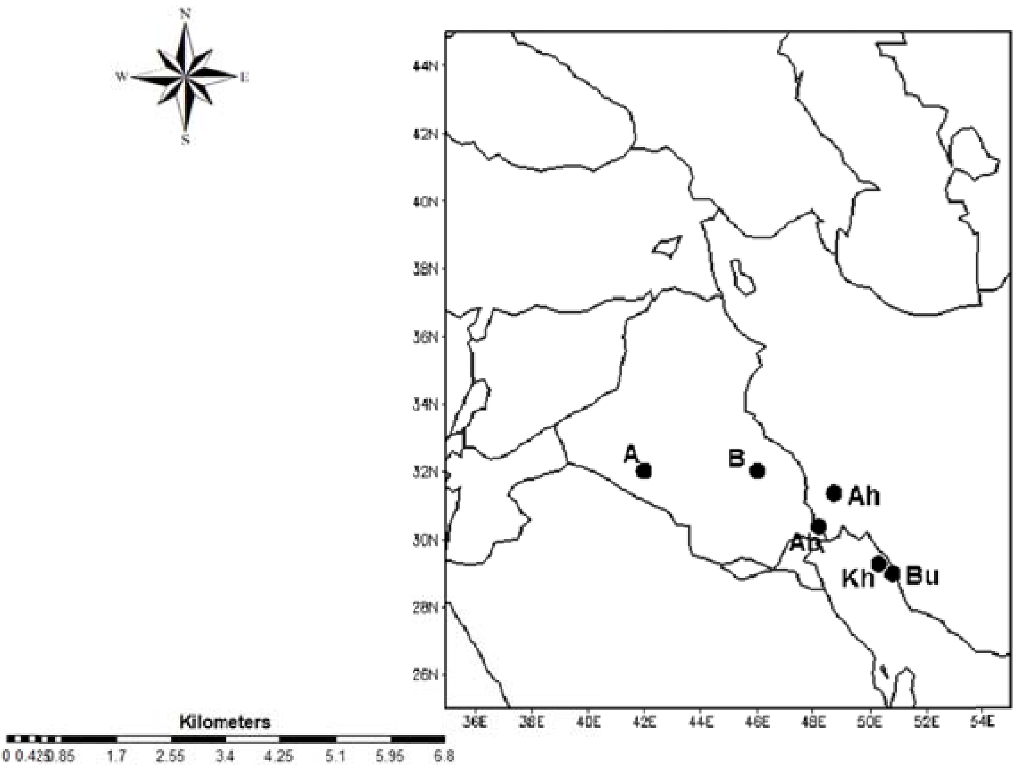


Fig. 1. Studied area in dust storm event. Situation of control stations (Ahwaz, Abadan, Kharg and Bushehr) and two region on Iraq (A, B)

Table 1. Location of Abadan, Ahvaz, Kharg and Bushehr stations

Station	longitude	latitude	Elevation (m)
Abadan	48.21	30.37	6.6
Ahvaz	48.74	31.34	22.5
Kharg	50.31	29.25	-1.2
Bushehr	50.81	28.96	9

The ECMWF data was also used for synoptic analysis. These data are derived by 0.75 × 0.75° resolution for the study area and based on them, the mean sea-level pressure (hPa), geopotential height of 500hPa level (m) and 10m wind (m/s), as well as horizontal (m/s) and vertical (pas/s) wind speed with geopotential height (m) at 925 hPa (762 m) were separately plotted. Since the formation of low-level jet streams plays an important role in the formation and transportation of dust from Iraq to Iran, the 925 hPa level was selected in the studies. This level well represents the position and speed of the low-level jet stream. The wind speed at this level can be a good indicator of wind speed variations in the lower parts of the troposphere. In addition to the synoptic structure and in order to further analyze the 10 m wind speed to determine the wind speed threshold, a profile of horizontal wind representing the low-level jet stream and a wind rose introducing the prevailing wind will be provided. The analysis is done in two parts: in the first part, the conditions for the formation of dust on Iraq and its transportation to Iran is considered, and the second part shows the conditions for the transportation of dust on Khuzestan and Persian Gulf. The HYSPLIT model was used to investigate the trajectory and source of storm. The HYSPLIT model is one with two Lagrangian and Eulerian approaches that can track the previous trajectory of particles in the atmosphere. The storm trajectory in this model was considered for 700 and 1500m elevations and the backward time is 24 h. In this model, the control station is Ahwaz and Kharg Island.

The DREAM model is another one used in this study, which is a meteorological model used to simulate or forecast weather in dust storms. This model is solved based on the nonlinear finite Eulerian differential equations for the dust mass continuity equation. Dust concentration is one of the governing diagnostic equations in atmospheric numerical prediction models. The output of DREAM model is the horizontal visibility over a 6-hour period.

Results and discussion

Variations of horizontal visibility in region

Table 2 shows the observation data for horizontal visibility at three stations of Abadan , Ahwaz and Kharg during February 18-19. On February 18, at 03 UTC, the horizontal visibility in the cities of Ahwaz and Abadan dropped to 3,000 m, and in the next hours (06, 09 and 12), the horizontal visibility in Ahwaz was reduced to 500 m. In the next few hours, the horizontal visibility caused by dust was increased, but the dust was continued in Abadan until 06 February 19 and in Ahwaz until 15 February 19. It should be noted that at 12 UTC on February 19, the horizontal visibility in Ahwaz reached zero. Afterwards, the visibility in both cities was increased and the dust conditions were not seen.

Table 2. Horizontal visibility in Abadan, Ahvaz and Kharg. Wind speed (m/s) and direction (degree). February 18 and 19 , 2017

Data	Time (UTC)	Abadan			Ahvaz			Kharg		
		Wind direction	Wind speed	Visibility	Wind direction	Wind speed	Visibility	Wind direction	Wind speed	Visibility
18-Feb-17	0	NW	4	10 Km	NE	1	10 Km			
18-Feb-17	3	W	4	3000	NW	3	2500	NW	12	10 Km
18-Feb-17	6	W	4	500	W	2	500	NW	10	10 Km
18-Feb-17	9	NW	3	2000	NW	2	500	NW	8	10 Km
18-Feb-17	12	W	5	3000	W	2	700	NW	7	3000
18-Feb-17	15	NW	4	1800	W	2	1000	NW	8	1000
18-Feb-17	18	N	3	3000	NW	1	1000	-	-	-
18-Feb-17	21	N	1	2500	NW	1	1400	-	-	-
19-Feb-17	0	W	1	2500	S	1	1500	-	-	-
19-Feb-17	3	W	2	2000	NW	2	1500	N	4	1200
19-Feb-17	6	NW	3	5000	SE	1	1100	NW	6	1400
19-Feb-17	9	NW	5	10 Km	N	2	2800	NW	7	1400
19-Feb-17	12	NW	3	10 Km	NW	3	0	NW	7	2000
19-Feb-17	15	W	2	10 Km	W	2	7000	NW	6	4000
19-Feb-17	18	-	0	10 Km	W	1	10 Km	-	-	-

In Kharg Island, the visibility began to decline at 12 UTC on February 18 and continued until 15UTC February 19. Hence, horizontal visibility in Kharg is observed 9 h after the declined visibility in Ahwaz and Abadan, which is due to the spread of dust to the east and south-east. The end time has also a 9 h difference from Abadan. Ahwaz experienced the highest reduction in visibility on February 18. During these two days, the wind direction at all three stations was north, northwest and west, which will be compared with the result of the HYSPLIT model in the next section. It was only in Ahwaz on February 19 that the wind direction was south and south-east and the visibility was reduced to zero. Therefore, the local conditions and the change in local wind direction appear to be effective in the process, resulting in a reduction in visibility. Also, wind speed in Ahwaz is much lower than other two cities.

Formation of dust on Iraq and its transportation to Iran

The output of DREAM model shows reduced horizontal visibility on Iraq (Fig. 2a). Also the analysis of GRB images obtained from the EUMETSAT satellite at 18 UTC on February 17 represents the formation of a concentrated dust core in the central parts of Iraq (Fig. 2b). As such, the model output and satellite image are consistent. Fig. 3a and b shows the horizontal visibility of the Dream model at 00-06 UTC on February 18 (Fig. 3a). In this figure, the reduced horizontal visibility in the southwest of Iran to less than a kilometer is evident, which is consistent with the horizontal visibility reports of the EUMETSAT satellite images and the national meteorological organization (Fig. 3b).

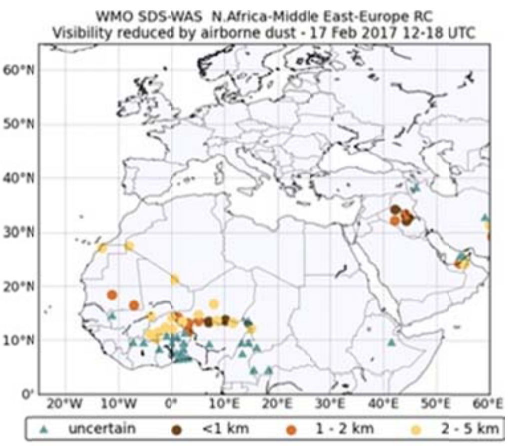


Fig. 2a. DREAM output, 17 Feb 18UTC, 2017

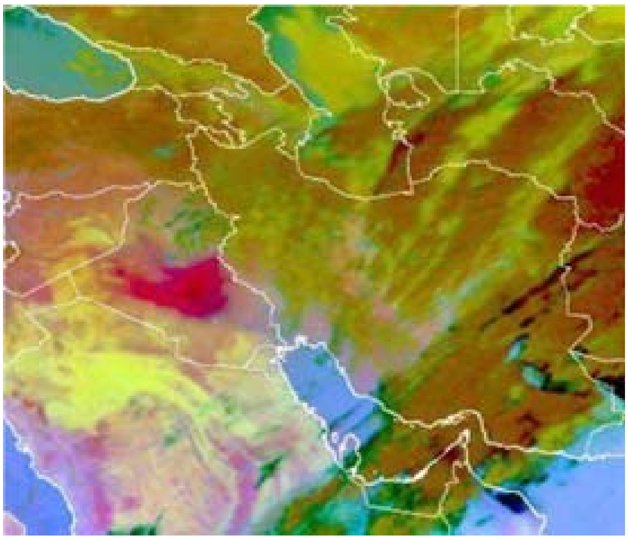


Fig. 2b. EUMETSAT image, 17 Feb 18UTC, 2017

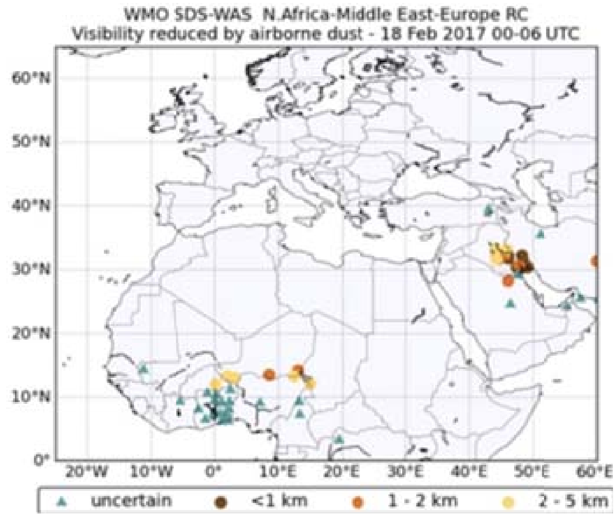


Fig. 3a. DREAM output, 18 Feb 06UTC, 2017

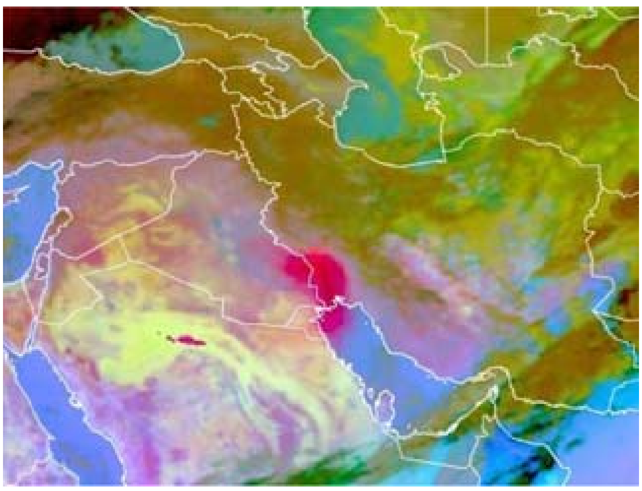


Fig. 3b. EUMETSAT image on 18 Feb 06UTC, 2017

Synoptic analysis

In the first step, the analysis of synoptic conditions 6 h before the formation of dust will be investigated (at 12 UTC on February 17, no dust is seen on Iraq - not shown). On February 17, at 12 UTC, a 1010 hPa low-pressure center is seen in eastern Iran, with a 1015 hPa trough extending to the northwest of Iran and parts of Iraq. On the other hand, a high-pressure tongue from the Black Sea with 1028 hPa value is extending towards southern Iraq, and hence, the northwest winds are formed on Iraq. Also, the geopotential height pattern for the 500 level shows a deep trough of northeastern-southwest direction on Iraq and western Iran (Fig. 4a). At 925 hPa, the maximum wind speed is 12 m/s (24 knots) in parts of northwestern Iraq and parts of Syria. Similar conditions are found in the northwest of the Persian Gulf, which is accompanied by the downward currents of vertical wind component (Fig. 4b). As such, the formation of northwest wind at 12 m/s in 925 hPa level in parts of Iraq and Syria leads to the formation of dust storms. Due to the increase in wind speed in parts of Syria, these areas can also be considered as contributing to dust formation.

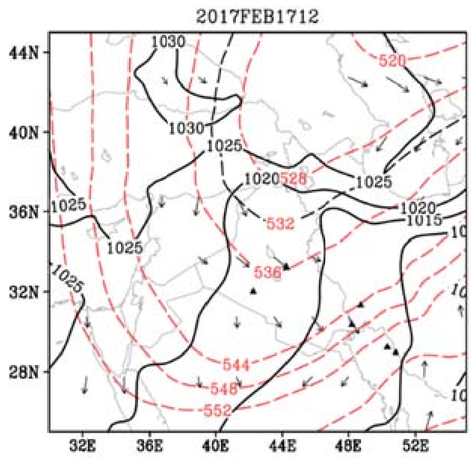


Fig. 4a. Mean sea level pressure (black) hPa, geopotential (red) at 500 hPa, 10m wind direction (arrow) m/s, 17 Feb 12UTC, 2017

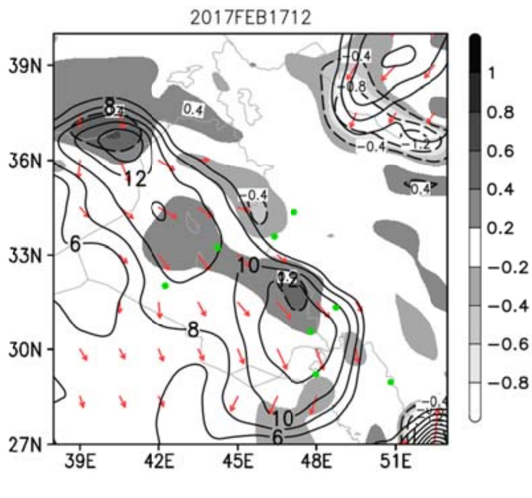


Fig. 4b. Wind speed (black) m/s and direction, gepotentail (red) Dm, vertical wind (sahded) at 925 hPa, 17 Feb 12UTC, 2017

At 18 UTC on February 17 (dust formed on Iraq, Fig. 2), the pressure pattern is similar to 12 UTC, but the strengthened north high-pressure (center pressure in the north of the Black Sea is 1030 hPa) and the 1025 hPa center on Syria can be seen that despite the increased pressure in the studied area, the pressure gradient was increased. The trough axis in the 500 hPa level has slightly turned to the east, extending north-south direction (Fig. 5a). At 925 hPa level, the maximum wind speed center is increased by 2 m/s from 6 hours ago (the maximum wind speed reaches 14 m/s in northern and eastern Iraq), and the maximum wind center in eastern Iraq is accompanied with the downward component of the vertical wind speed (Fig. 5b). Increasing the wind speed increases the dust intensity on Iraq.

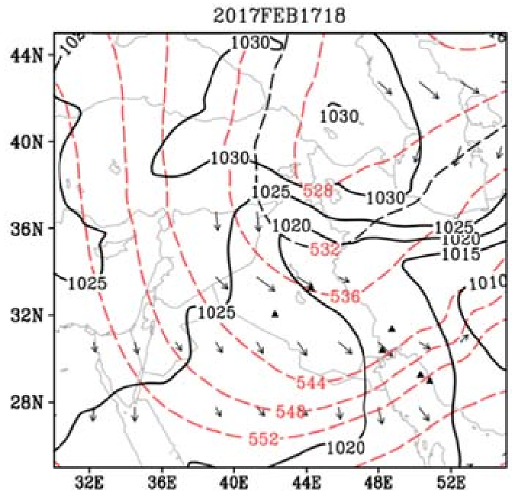


Fig. 5a. Mean sea level pressure (black) hPa, geopotential (red) at 500 hPa, 10m wind direction (arrow) m/s , 17 Feb 18 UTC, 2017

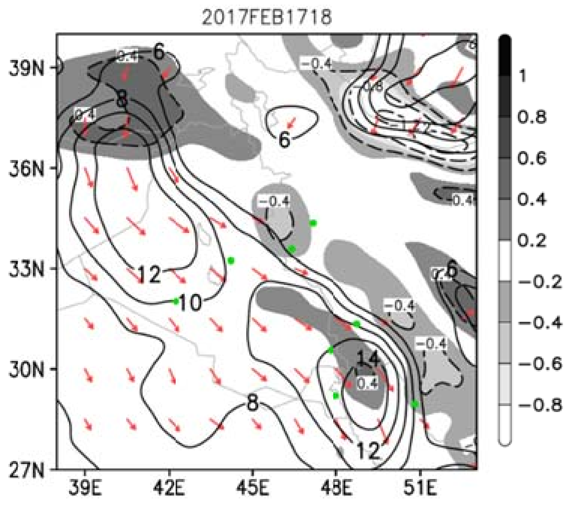


Fig. 5b. Wind speed (black) m/s and direction, gepotentail (red) Dm, vertical wind (sahded) at 925 hpa, 17 Feb 18 UTC, 2017

On February 18, at 00 UTC, as the high pressure is located on Russia, its trough is spread to Syria and Iraq, and in the center to the west of Iran, a low-pressure trough is formed, and along which the northwest winds on Iraq are observed. The wind continuation on Iraq leads to the transportation of dust to Iran (Fig. 6a). At 925 hPa level, the wind speed is 12 m/s throughout Iraq, and in the central and southeastern parts of Iraq, the low value of vertical speed is seen (Fig. 6b). The downward vertical speed causes the dust to remain at the lower levels of the atmosphere. In this way, the continuity of the above-mentioned synoptic structure and the formation of northwest winds lead to the transportation of dust to Iran. The system studied in the formation of dust is of post-front type that is according to the studies by other researcher [2].

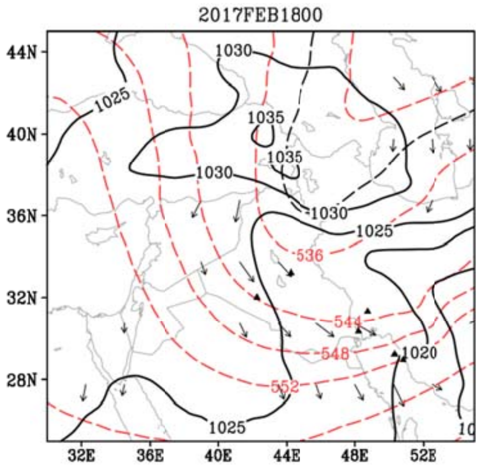


Fig. 6a. Mean sea level pressure (black) hPa, geopotential(red) at 500 hPa, 10m wind direction (arrow) m/s , 18 Feb 00 UTC, 2017

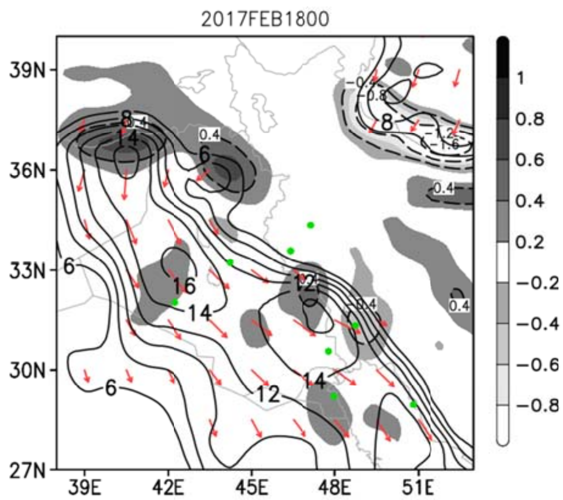


Fig. 6b. Wind speed (black) m/s and direction,gepotentail (red) Dm, vertical wind (sahded) at 925 hpa,18 Feb 00 UTC, 2017

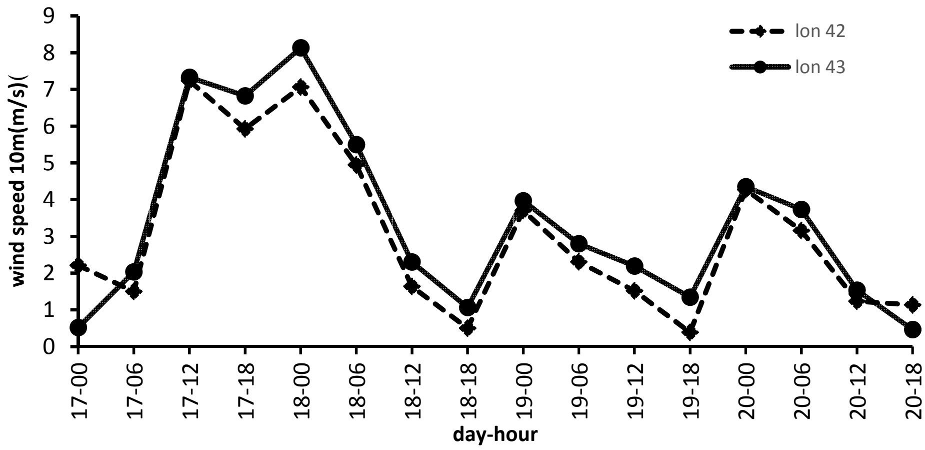


Fig. 7. 10 m wind speed in 32°N, 42°E and 43°E

Also, according to Fig. 7, which indicates the change in 10 m wind speed in latitude 32° for longitudes 42-43°, the increase in wind speed from 6 UTC on February 17 to 12 UTC is from 2 to 8 m/s on the same day. Therefore, with increasing surface speed, the soil condition is prone to erosion, rising dust particles in these areas (Iraq). The 10 m wind speed is increased 6 m/s during 6 h.

The threshold 10 m wind speed for rising dust in the northeastern Iraq is 8 m/s as determined by other researcher [4]. Until 00 UTC on February 18, the surface wind speed is still high and then it is decreased. Although fluctuations occur on February 18 and 19, wind speeds is not increased by more than 4 m/s. In this way, it can be seen that the increase in wind speed to 8 m/s causes the formation of dust storms. It should be noted that the wind speed is reduced at 18 UTC on February 18, 19 and 20 when the wind speed approaches zero.

Role of low-level jet streams in formation and transportation of dust

The formation of low-level jet stream is an important factor in the transportation of dust. Since the dust is transported to Iran at the next hour, on February 17, at 18 UTC, the vertical wind profiles are plotted to examine the conditions of low-level jet stream. The horizontal wind profile is displayed at latitude 32° north (study area) in Fig. 8a. In this figure, the maximum wind speed of 15 m/s at 900 hPa level is seen at 41-43° longitudes in the figure, which indicates the change in the wind field and the increase in wind speed in the lower parts of the atmosphere. Also, at 47° longitude, another maximum wind speed is formed at 925 hPa. The vertical of wind shear at 32° N and 43° E are shown in Fig8 .b. The existence of wind shear is one of the important components in determining the existence of low-level jet streams. Thus, the formation of low-level jet stream on Iraq is a major factor in the transportation of dust to Iran.

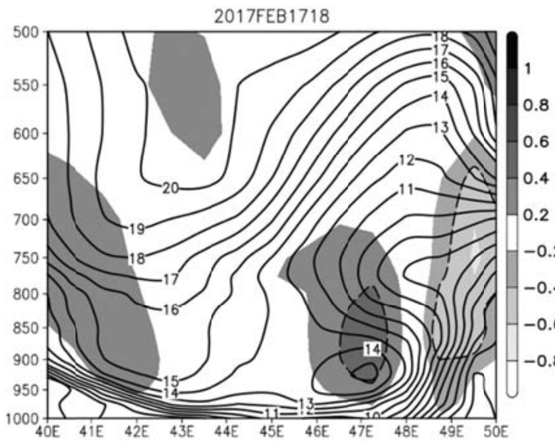
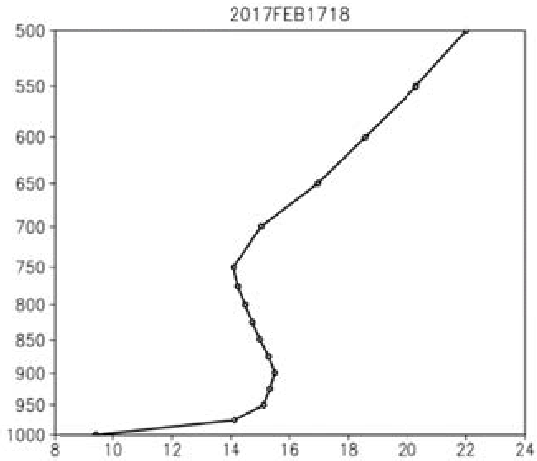


Fig. 8a. Wind speed (black) and direction (arrow) cross section, vertical motion (shaded) pa/s in 32°N , 17 Feb 18UTC, 2017



Wind speed profile in 34°N and 43°E, 17 Feb 18UTC, 2017

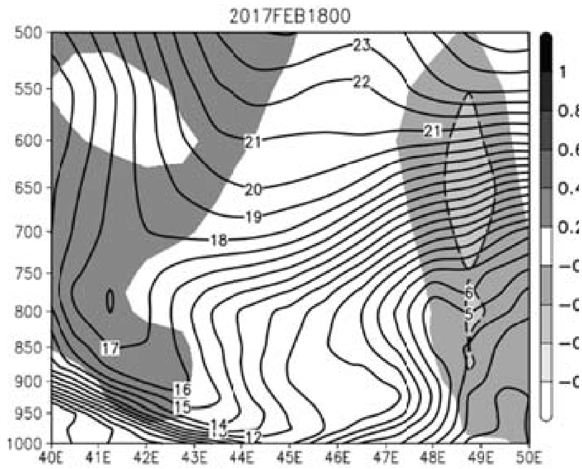


Fig. 9a. Wind speed (black) and direction (arrow) cross section, vertical motion (shaded) pa/s in 32°N , 18 Feb 00UTC, 2017

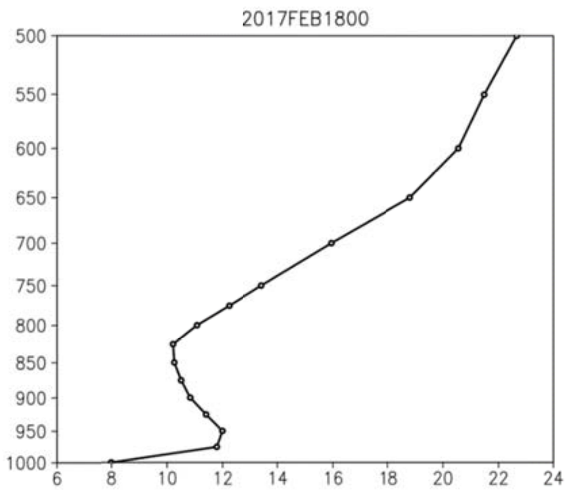


Fig. 9b. Wind speed profile in 34°N and 43°E, 18 Feb 00UTC, 2017

The time series in the wind speed in one point over Iraq with the latitude of 32° and longitude of 42° (Fig. 10a) on and on Ahwaz (Fig. 10b) is plotted. Wind speed at 900 hPa was increased to 16 m/s during 12 UTC on February 17 to 00 UTC on February 18 (Fig. 10a). According to Figs. 8 and 9 and 10, the role of low-level jet stream in the transportation of dust to Iran can be verified. The existence and impact of low-level jet stream on the dust transportation are consistent with previous studies [15] [12] [4].

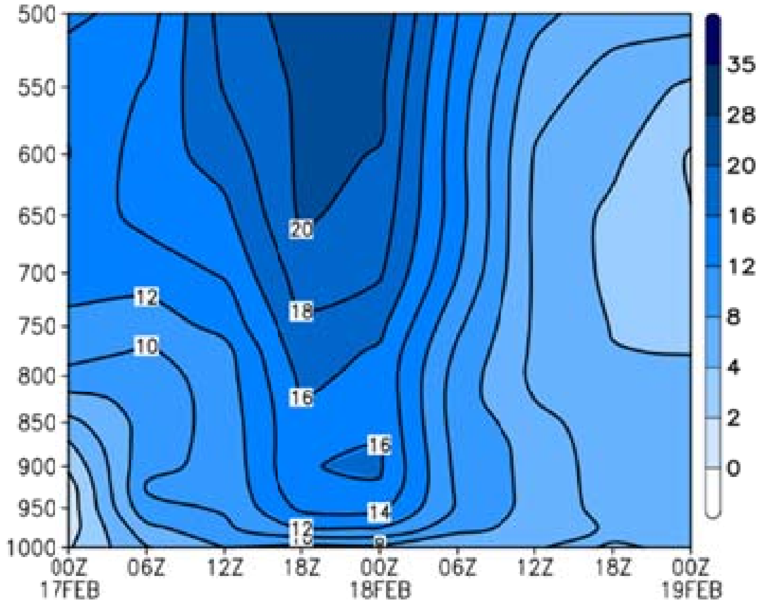


Fig. 10a. Meteogram of wind speed, 32°N and 42°E (Iraq),

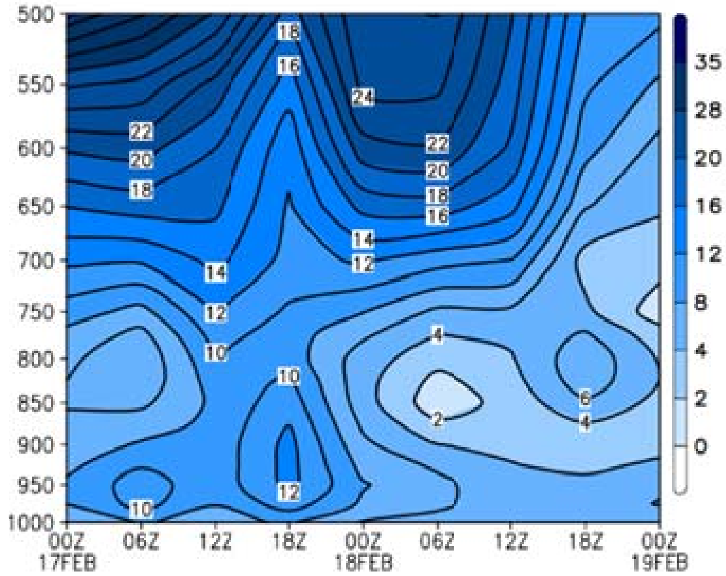


Fig. 10b. Meteogram of wind speed, Ahvaz, 17 to 20 Feb, 2017

Conditions for dust transportation to Persian Gulf

Fig. 11 shows the DREAM model output and the EUMETSAT satellite image displaying the presence of dust in southwestern Iran and the northwestern parts of the Persian Gulf. In this way, the synoptic conditions and wind field for the past hours led to the transportation of dust to these areas.

The wind rose plotted at the Ahwaz station shows the prevailing wind in the northwest at speeds ranging from 4 to 7 m/s, which is consistent with the synoptic analysis of the northwest wind in the region (Fig. 12a). Also, the HYSPLIT model output (Fig. 12b) confirms the northwest winds at Ahwaz station and shows the trajectory of storm from Iraq to Iran. In this way, the wind rose and the HYSPLIT model well show dust transportation along with northwest winds and are consistent with Figs. 12a and 12b.

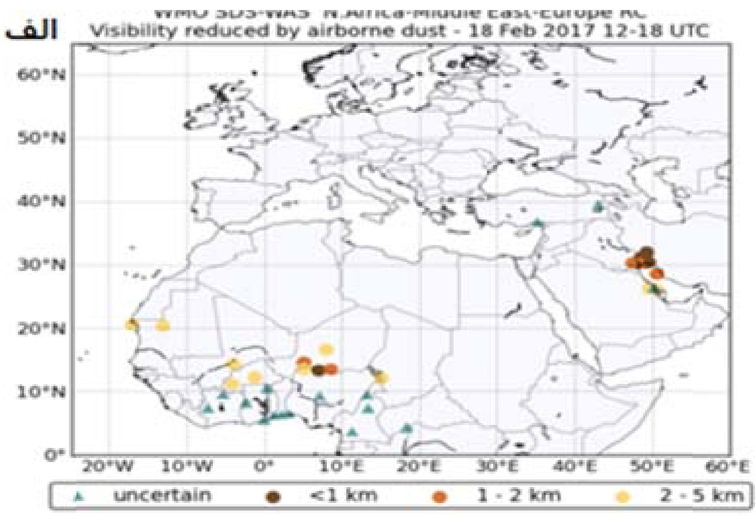


Fig. 11a. DREAM output, 18 Feb 18UTC, 2017

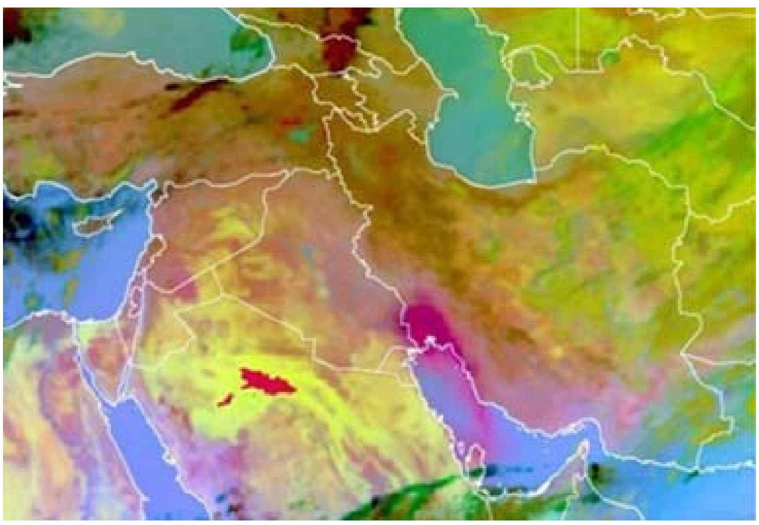


Fig. 11b. EUMETSAT image on 18 Feb 18UTC, 2017

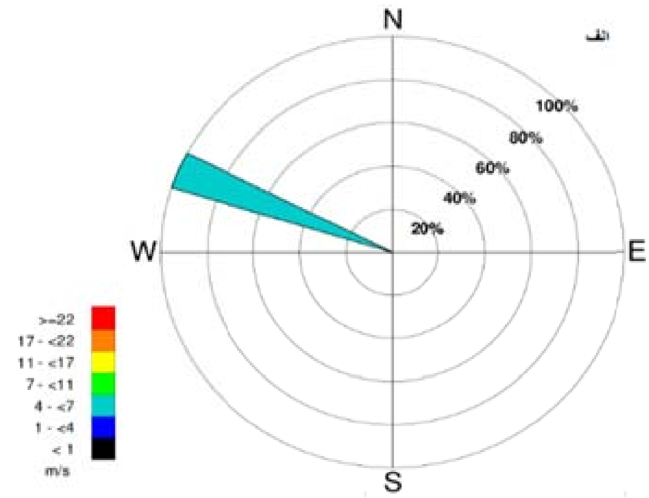


Fig. 12a. Wind rose in Ahvaz, 17 Feb 18UTC, 2017

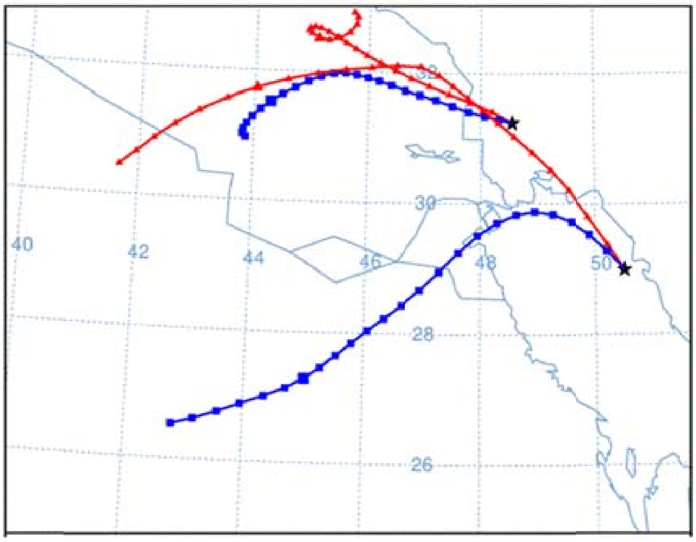


Fig. 12b. HYSPLIT , in Ahvaz, 17 Feb 18UTC, 2017

In the following, the synoptic conditions leading to the transportation of dust to the Persian Gulf are analyzed. Fig. 13a shows the sea-level pressure structure, reduced extension of low-pressure tongue in the western parts of Iran and Iraq, and the extension of the high-pressure tongue to northern Saudi Arabia at 18 UTC on February 18 shows which is accompanied by a decrease in the 10 m wind speed in southeastern Iraq compared with the previous hours. The 10 m wind direction is towards the Persian Gulf, but in Ahwaz, the direction of wind changed to the northeast direction (Table 1), which seems that the local conditions intensify the dust in the area (confirmation of HYSPLIT model at 700m height). At 925 hPa level, the maximum wind speed is 8 m/s in the northwest of the Persian Gulf, which contributes to the transportation of dust to this area (Fig. 13b).

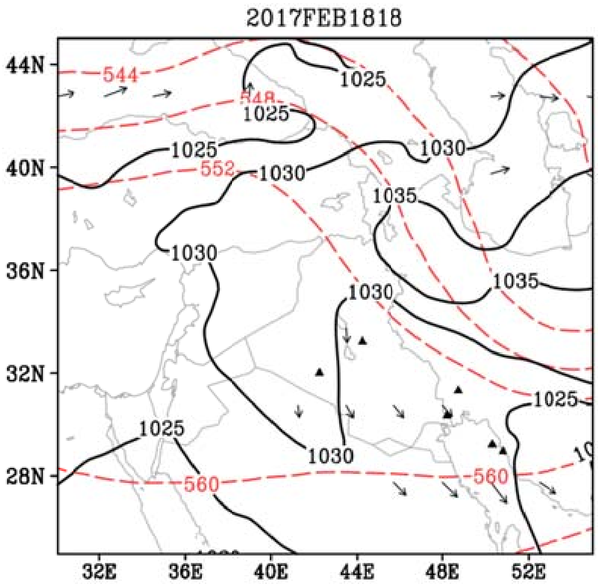


Fig.13a. Mean sea level pressure (black) hPa, geopotential (red) at 500 hPa, 10 m wind direction (arrow) m/s, 18 Feb 18 UTC, 2017

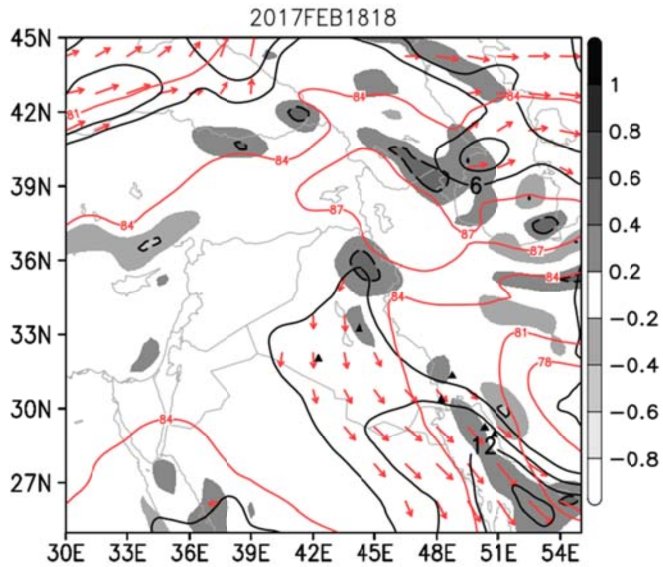


Fig. 13b. Wind speed (black) m/s and direction,gepotentail (red) Dm, vertical wind (sahded) at 925 hpa, 18 Feb 18 UTC, 2017

Throughout southwestern Iran and major parts of Iraq, the downward vertical speed is observed, which contributes to intensify the dust.

Figs. 14a and 14b are the wind rose and output of the HYSPLIT model for Kharg Island, which are similar to Figs. 12a and 12b. According to the output of the HYSPLIT model, the dust was transported to the Persian Gulf from Iraq (Fig. 14a and b). This figure shows the particle trajectory and the dust transport to Kharg and on the Persian Gulf from Iraq in the northwest direction.

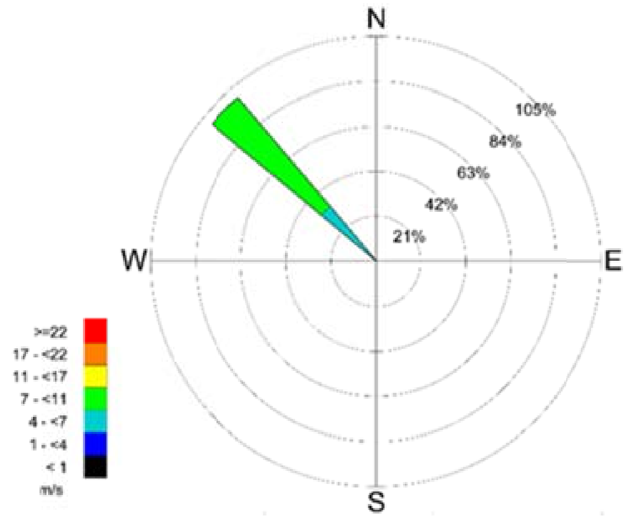


Fig. 14a. Wind rose in Kharg Island, 18 Feb 00UTC, 2017

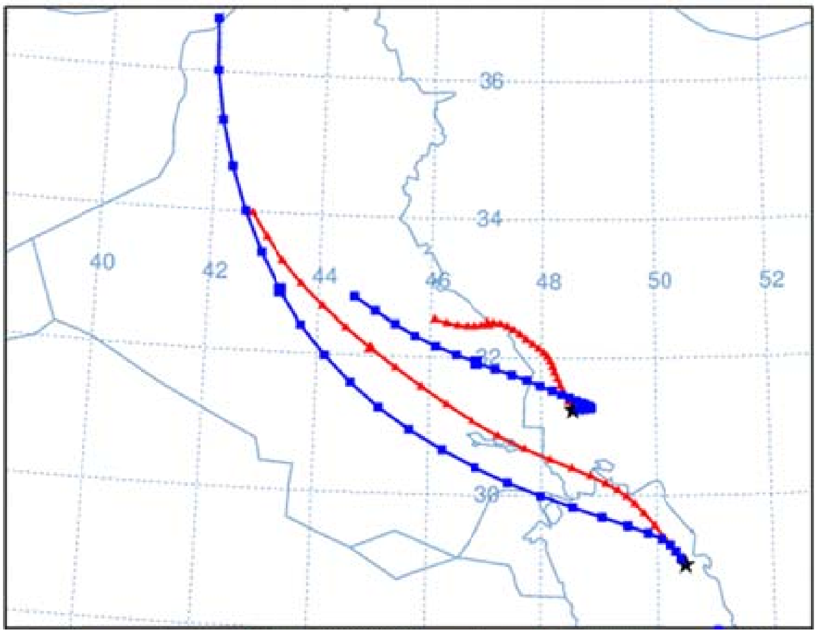


Fig. 14b. HYSPLIT, in Kharg Island, 18 Feb 18UTC, 2017

The DREAM model also shows a continued decline in visibility in Khuzestan province, although its intensity is decreased and the horizontal visibility is decreased on the Persian Gulf, which indicates the spread of dust to those areas (Fig. 15 a). On February 19, EUMETSAT satellite image shows dust in southwestern Iran and northwest Persian Gulf (Fig. 15b).

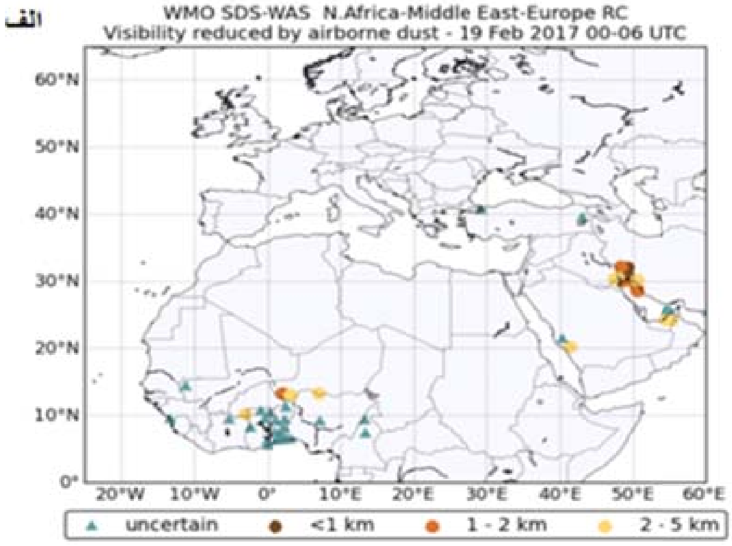


Fig. 15a. Mean sea level pressure (black) hPa, geopotential (red) at 500 hPa, 10 m wind direction (arrow) m/s, 19 Feb 12UTC, 2017

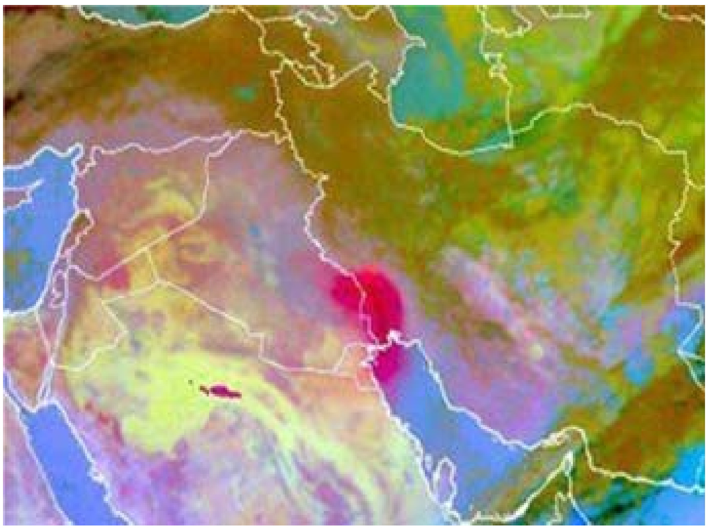


Fig. 15b. Wind speed (black) m/s and direction, gepotentail (red) Dm, vertical wind (sahded) at 925 hpa, 19 Feb 12UTC, 2017

According to Table 1, on February 19, from 00 to 09 UTC, the reduced visibility in Ahwaz and Abadan was maintained, which is consistent with satellite images. In addition, based on the HYSPLIT model, the particles continue to be transported from Iraq to Iran (Fig. 12 and 14b). As seen from the satellite image, on February 19, dust was transported to the Persian Gulf. Reviewing the synoptic conditions over the past few hours, it appears that the current conditions and continuation of northwest winds on Iraq (HYSPLIT model) have led to the transportation of dust to the Persian Gulf. The synoptic structure was still continued until 06 February 19, and further parts of the Gulf are affected by dust (not shown). Until February 19 at UTC 15, dust is seen on the Khuzestan province and parts of the Persian Gulf (not shown), although it is decreased in intensity in Khuzestan province. Based on the Dream image, up to 18 UTC on February 20, there was no reduction in visibility in the desired parts, and the dust storm in the area has completely disappeared (not shown).

Conclusion

The results of the study on the storm in February 17, 2017 showed that as the low pressure is located in the eastern parts of Iran and the low-pressure trough is extended to the west of Iran and parts of Iraq, as well as with the formation of a high-pressure center on Syria and the extension of the high-pressure ridge towards the west and south of Iraq, the pressure gradient is formed in the central parts of Iraq and the wind speed is increased. Twelve hours prior to the formation of dust in Iraq deserts, with an increase in the 10 m wind speed to 14 m/s (28 knots) along the northwest, the dust particles are liable to enter the atmosphere. The continuation of these conditions and the presence of northwest winds on Iraq have brought dust to the southwest of Iran and the Persian Gulf. Six hours prior to the arrival of dust to the Iranian borders, the low-level jet stream was formed at latitude 32° and 41°-43° east longitudes, which is an important factor in the transportation of dust. The 10 m wind speed to raise the dust was 8 m/s. The output of the Dream model well represents the formation of dust on Iraq and its transportation to Iran, and the estimated reduction in visibility is consistent with the horizontal visibility data of the national meteorological organization and is a reliable model for studying the dust storms. The HYSPLIT model confirms the particle trajectory at 700 and 1500 hPa based on the northwest winds in the direction of dust transportation to Iran. However, on March 19, the particle trajectory at 700 hPa level shows a local change for Ahwaz. Comparison of horizontal visibility in Ahwaz and Abadan, as well as the study of HYSPLIT model output and the 925 hPa wind field indicate that given the conditions in Ahwaz, the local dust is also formed and the dust density is increased. The 925 hPa wind field, HYSPLIT model output and the wind rose plotted at the two control stations are in full agreement.

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Competing interests

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Ethical considerations

It is also an original article and has not previously been published by any other publication.

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