Source of dust and sand storms in the southwest of Iran and Persian Gulf region

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Abstract

Dust storm is a large-scale environmental problem which affects on the healthiness and livings of communities in the world. Numerous heavy dust and sand storms happen in the south and southwest of Iran, near the Persian Gulf. In recent years, lots of dust storms in this area have caused enormous damages and heavy casualties inflicted on the inhabitants. Reduced visibility, strong winds, red sky, hail fall, and severe thunderstorms are the results of dust and sand storm. This paper has attempted to conduct dust storms, as well as short-term and long-term effects of the storm based on the statistical and analytical methods. The satellite images from Physical Meteorological Observatory showed that the dust storms based on the synoptic scale of meteorology were associated with cold fronts and cyclones' activity. The sand and dust storms occur when strong storms blowing from arid regions hit the cold fronts and make instability in the air flow.

Keywords: Dust storm; Persian Gulf; Satellite images; Climate model; Southwest of Iran.

1. Introduction

More than 40 percent of the continents in world are in the arid regions with low precipitation and nearly one billion people live there. Wind is a global process that is generated by air flow and temperature changes in the environment.

Wind is strongly influenced by vegetation and it reduces by increasing the vegetation. Usually within rainforests, the air flow (wind) is very limited, so it seems that there is no wind at all (Trikar, 1990). The wind can move any particles in different sizes. Displacement and transport of particles by the wind depend on the wind speed and the particles' size and their density. The larger and heavier particles need higher wind speed to move. With increasing wind speed, in addition to fine particles, larger particles are transported as well. Thus, greater volume of particles is transported at higher wind speeds. In fact, size, shape and density of particles determine how the sand and dust move to. Suspended particles are the dust smaller than 0.01 mm and clay particles with a diameter of smaller than 0.002 mm.

These small and light particles can be raised to an altitude of six kilometers away from the Earth's surface and travel a distance of over 6000 km. The

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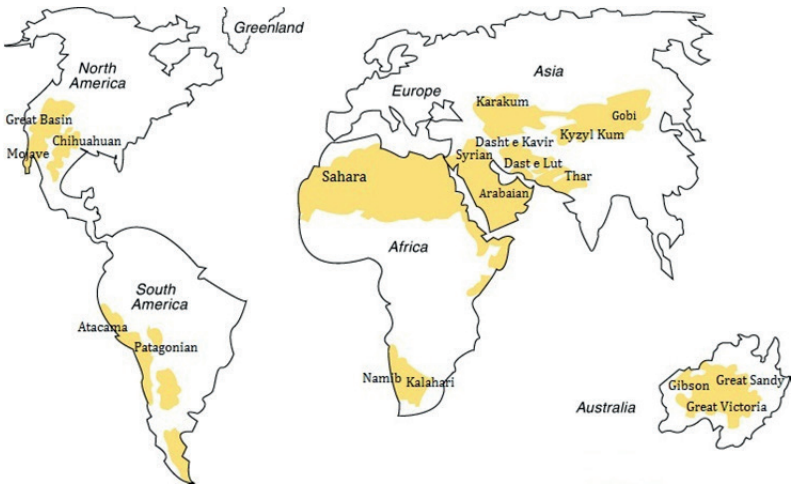

Figure 1. The great deserts of the world and Sahara desert in the north of Africa by National Aeronautics and Space Administration (NASA)

study results by Geological Department of Oxford University showed that the dust particles are often alkali (alkaline) with about 0.01 mm diameter and are suspended and seen in red color in the atmosphere above the ground, and generally this leads to visibility reduction that indicates the occurrence of a real dust storm.

Real deserts are rarely the source of dust storms because the particles can be transported in any way, and then deposited again in another part of the area, but the deserts' margins are often the main source of dangerous dust storms that sweep periodically or regularly rough places and landscapes across the Earth's surface and have erosion and devastating effects on them. The mechanism of particles transportation varies according to their size. The fine-grained particles are suspended in the air and the sand particles are often moved on the Earth's surface, with throwing, rolling and sliding. Two important points are as follows:

The mechanism of sediment transport (sand, dust and particles of organic materials) by the wind, have been thoroughly studied and understood and must seek the places on Earth where the sediments situation have been stabilized and the particle transfer or its transportation is inconsiderable or impossible.

More attention to the arid areas destruction is necessary, due to economic and social aspects. In this case, the focus is not just on the land, but also it should be more emphasized about the people who use the land (Grainger *et al.*, 2000)

Dust and sand storms are natural disasters, which widely occur throughout the world and in arid and semi-arid areas, especially in subtropical latitudes. Wide distribution and desert landscapes (Figure 1) indicate that these areas are a very important source of dust storms in the past, but in recent years, human performance have been another source of this problem. Dust storm occurs when the humans cause too many clutter in dry areas. There are also several areas where dust storms originated from. These arid areas are in accordance with desertification in the regions. The world's great deserts, such as the Sahara, are the local or regional origin of the widespread distribution of dust and sand in the world.

Yaloon in 1996 showed that the origins of dust sedimentary are the Southern Europe and the North Africa. In addition, Nilsen in the same year represented that the Sahara regions are the main source of windy dust in the world. The dust which move westward over the Atlantic Ocean and northward in the north region of Sahara is in connection with several transition phases and sedimentation cycles. It has been indicated that the arid and semi-arid regions around the Arabian Sea are also the major

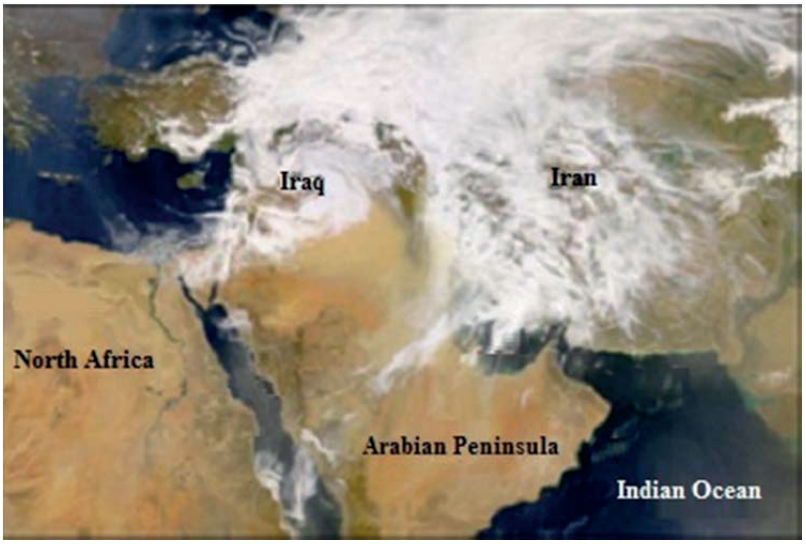

Figure 2. Satellite image of dust in the Middle East and the Red Sea

causes of dust in the universe. The storm formation in India, Pakistan, Iran, and the Arabian Peninsula and its transmission by the wind lead to deposition of dust in the Arabian Sea. Furthermore, the dust which generate over China causes deposition in the Pacific Ocean (Grainger *et al.*, 2000). Figure 2 shows the satellite image of dust in the Middle East and the Red Sea.

In recent years, several major dust storms occurred in southwestern of Iran near the Persian Gulf; for example, the occurrence of different storms in March 25, 2003; April 17, 2003; April 12, 2007; and May 17, 2007, caused some negative effects on air quality and lots of damages to the human life in the local and surrounding areas. Since 1970, the scientists identified the prevalence of dust storms through satellite images using infrared waves (IR) in two different methods:

- Visible and near infrared technique (VIR)
- Window technique or thermal IR (TIR)

Shenk and Curran (1974) investigated the dust storm identification on the Earth and water using visible satellite and infrared measurement method. They showed that to depict the dust's borders, the infrared measurements for the ocean covered with dust and without dust were not appropriate. According to the Idso in 1976, the Saudi Arabia should be considered as one of the five known specific area of originating the intense dust storms in the world (Taghavi and Asadi, 2009).

Carlson in 1978 clearly represented the results from the analysis of satellite data in atmospheric chaos (turbidity) of dust spreads in Sahara. Several interesting features of dust spread in a very wide area, including the shape and approximate boundaries of the dust plume were visible in satellite images. Different regions where are the source of dust in the atmosphere were found by some researchers using remote sensing. In addition, observation of the surface dust was stated by Herman *et al.* (1997) and Total Ozone Mapping Spectrometer (TOMS) method was signified by Hsu *et al.* (1999) and Washington *et al.* (2003) as well.

2. Material and methods

2.1. Study area

Khuzestan province in the southwest of Iran is geographically located at 47º 40′ to 50º 33′ E (longitude) and 29º 57′ to 33° N (latitude). The province area is 6.4 million hectares and its capital city (Ahvaz) is in a height of 23 m above the sea level. The maximum and minimum altitudes of the province

are 3707 and zero meters, respectively. The average rainfall is 266 mm with the mean temperature of 26 °C. The province is in the vicinity of Iraq, but when the westerly winds-the prevailing phenomenon in the region-flows toward the province, pass over the countries of Syria, north of Saudi Arabia, and Kuwait.

2.2. Data

The data of dust storm over the study area obtained from Aqua satellite of Moderate Resolution Imaging Spectroradiometer (MODIS, 2007). Moreover, the data of dust storms during the years of 1960-2007 were obtained from online source, http://www.eumetsat.int/ website/home/Images/, and a study by Taghavi and Asadi (2009). Historical data of dust storms in Asia is also available at Chun *et al.* (2008).

3. Results and Discussions

Iran in recent years, particularly the southwest provinces such as Khuzestan, has witnessed a significant increase in the occurrence of dust phenomenon, so that the number of dusty days due to the entering trans-regional dust has increased from 12 days in 1998 to 13 days in 2008 and led to a considerable drop in air quality.

This phenomenon due to inherent characteristics of its particles can have environmental and climatic impacts on the different atmospheric and oceanic systems, and continents. Dust storms have important affects such as the effect of transferring "mineral aerosols" (suspended particles) on the minerals in soil, the variations of atmospheric resistance to solar radiation and the effects on the activity of phytoplankton in the oceans. Almost half of the mass are the particles with a diameter less than 2.5 µm and the studies on communicable diseases show

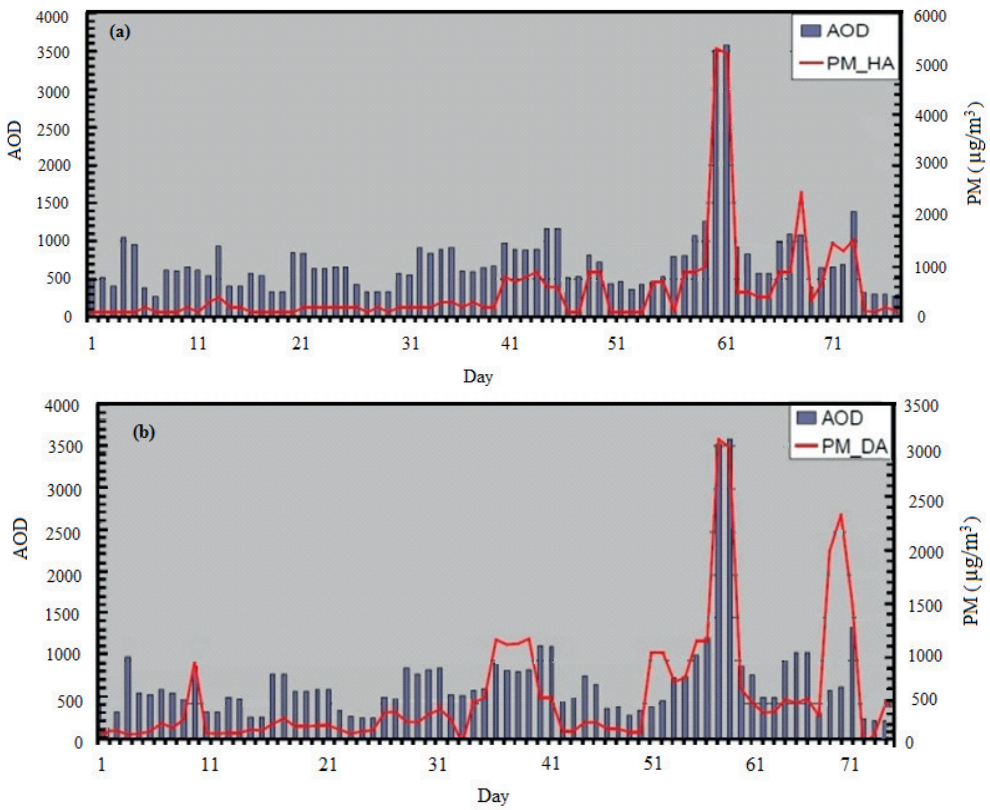

Figure 3. Comparison of AOD variations and (a) mean hourly of PM_{10} and (b) mean daily of PM_{10} in five stations

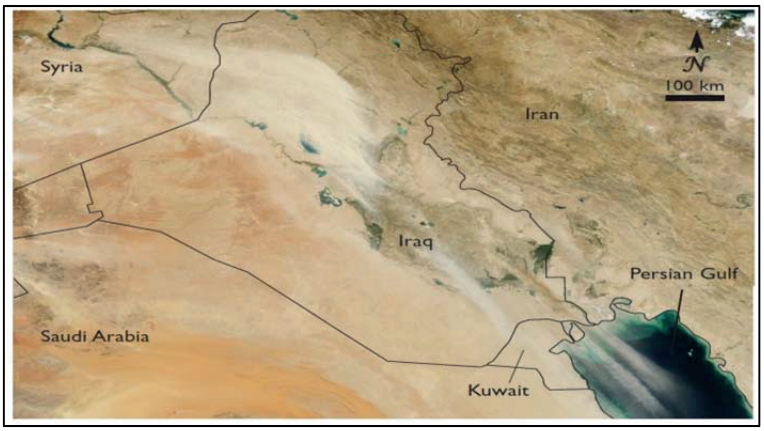

Figure 4. The spread of dust clouds over the countries of Iraq, Syria, Kuwait, and the Persian Gulf on August 7, 2005 (NASA, 2007)

a strong correlation of the amount of these particles with the general illnesses and patient mortality due to lung and heart problems.

The amount of particulate matter with a diameter of 10 μm or 0.01mm (PM_{10}) can represent that besides the spatial variations, the extremely temporal differences were observed in the parameters, so that the maximum of PM_{10} in Ahvaz airport station, in some hours was 5300μg/m^3 and its minimum of PM_{10} was 100μg/m^3 (Boac *et al.*, 2009). The spatial variability of this phenomenon can be due to the climate change and the added dust from local aerosol sources.

Figures 3a and 3b respectively show the comparison of variations of Aerosol optical depth (AOD) and the mean hourly particulate matter (PM-HA), and mean daily particulate matter (PM-DA) in Ahvaz stations (Rangzan *et al.*, 2014).

Dust storms often occur throughout the year in the regions such as the north of Africa and the southwest of Asia. As an example, dust clouds were vastly observed above the countries of Iraq, Syria, and Kuwait, as well as over the Persian Gulf in 7th August, 2005 (Figure 4).

The dust plume is measured using a quantity called "optical thickness" that is in compliance with its expansion (Figure 5). According to the data observed by MODIS from Aqua satellite, dust concentration is higher in upper atmosphere layers and more optical thickness.

Actually, using the continuous time autoregressive moving average (CARMA) model, the researchers forecasted dust storms and realized that this model is an effective forecasting tool to detect the occurrence of dust storm. In this model, using the receiver, the areas which were the potential source of mineral dust were identified which the dust storm came from the east of Mediterranean. TOMS' data showed that the Middle East, especially Ad Dahna region in the east and center of Saudi Arabia, is an important area for dust storm activity. In contrast to the frequency of dust storms, in the larger parts lots of rainfall will be happened. Obviously, the drier and hotter conditions, the more dust storms will be. One of the most important sources of dust storms in the world is the great deserts of the African continent such as Sahara. In these areas, dust storm is considered as a severe natural event that has negative impacts on human health, the products, and industrial activities.

By studying the frequency of dust storms during 1960-2007, their circulation properties in synoptic scale was investigated in the southwest of Iran and then the intensity of dust storms obtained from satellite images were compared with meteorological observations. Synoptic analysis of dust storms in the Middle East showed that the main dust or sand storms can be produced there. These storms

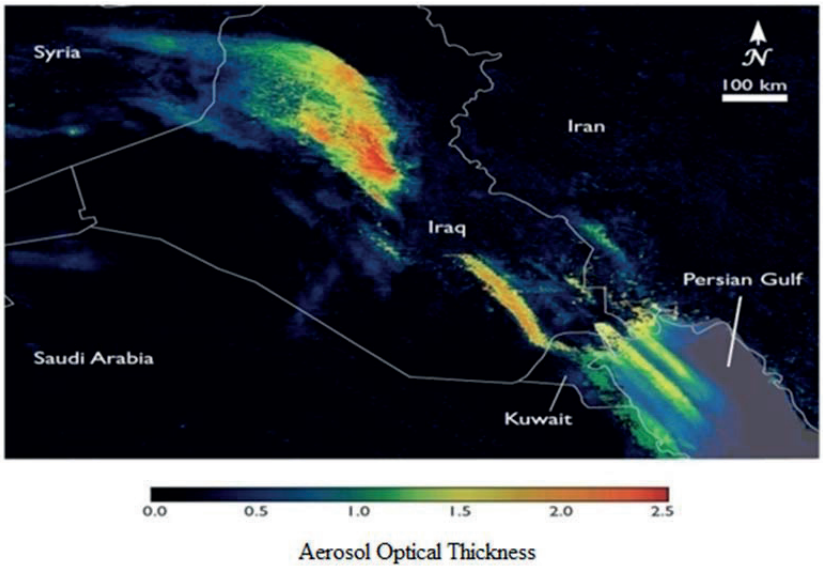

Figure 5. Comparison of the agreement of optical thickness of dust plume over Syria and Persian Gulf with its expansion (MODIS, 2007)

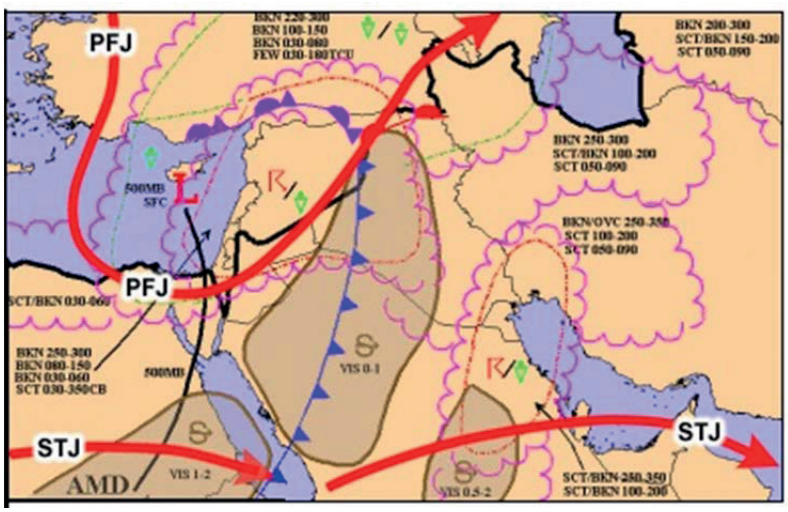

Figure 6. STJ moves from the south of Arabian Peninsula and PFJ moves from the Europe, in spring and summer (www.meted.ucar.edu)

generate when the sub-tropical jet (STJ) moves from the south of Arabian Peninsula and the polar front jet (PFJ) moves from the Europe.

The storms are common in spring and summer when the northwestern wind is dominant. Special topography and human activities in the region reinforce the frequency and intensity of the sand and dust storms. Funneling is a large air mass surrounded by the mountains in Iran and Turkey along with highland plateaus in Saudi Arabia, caused the funnel air flows from the Mediterranean to the Persian Gulf.

Dust and sand storms occur particularly when strong storms (mostly dry) are accompanied with cold fronts and subsequently with perturbations (Taghavi and Asadi, 2009). Actually, the maps by National Oceanic and Atmospheric Administration (NOAA) indicate the weather conditions for the occurrence of a front jet stream in the dust storms over the Middle East. Figure 7 indicates the severe

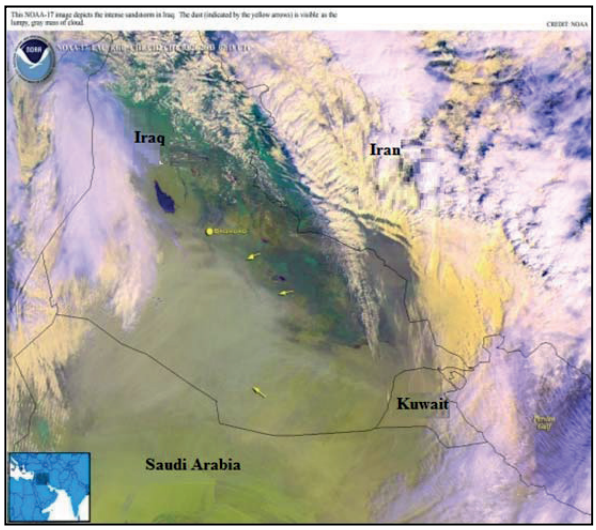

Figure 7. An unprecedented dust storm over the southwestern of Iran and the Middle East, on March 26, 2003

dust storm over the Middle East on March 26, 2003 reported by NOAA. The particular storm was a mid-latitude cyclone and the yellow arrows in the image show the dust storm movement (www.met-ed.ucar.edu).

The Figure 8 shows the water vapor (clouds) obtained from Meteosat5. A heavy and unprecedented dust storm in the last decade occurred in southwestern of Iran on March 26, 2003. In fact, the Meteosat5 has captured the water vapor caused by the storm on the Middle East and the Persian Gulf.

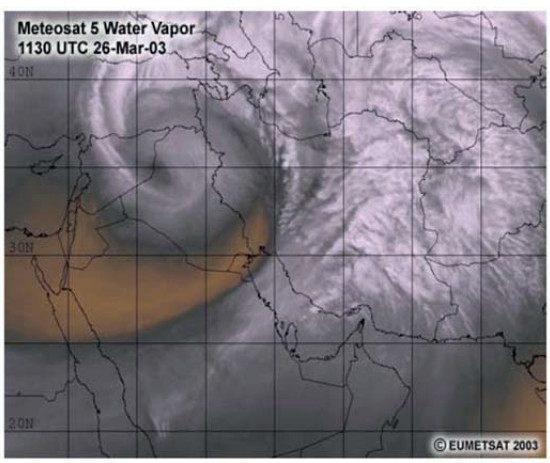

Figure 8. The water vapor by Meteosat5 over the Middle East and the Persian Gulf on March 26, 2003 (www.eumetsat.int)

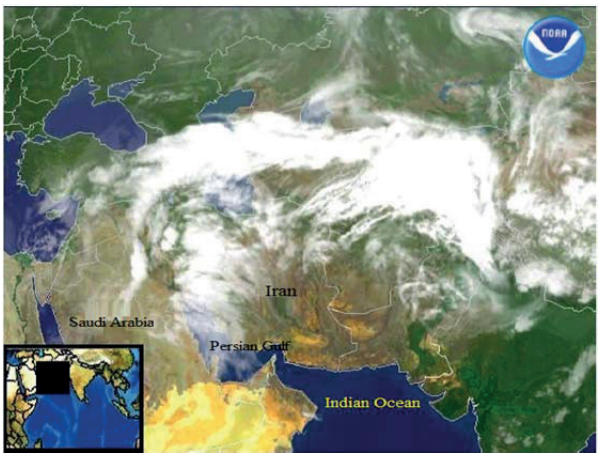

Figure 9. Low-pressure system along with the storms and rains in the west part and the southwestern of Iran, the Persian Gulf, and the Middle East (NASA, 2007)

In many areas, the dust storms categorized by the prefrontal and postfrontal winds mostly occur in winter and the dust storms caused by northerlies happen in summer. In the winter, passing another front behind this front leads to the strong northwesterly winds. So that the direction of the dust storm, that is called Shamal, will be from the west to the north. The storm or Shamal leads to a dangerous and expanded weather in the region. Some parts of the low-pressure system bring the storms and rainfall in the south-western of Iran and also some parts of the system bring the storms and rainfall in the Middle East region (Figure 9).

3.1. Dust Storm in the Persian Gulf on April 12, 2007 (based on observation and analysis model)

In the spring, the wind often blows in southwestern of Iran and the air is dry and the conditions are favorable for dust storms' development. In April 2007, a column of weak sandstorm from the northwestern of Iran brought sand and dust in are the Middle East from the deserts in Saudi Arabia and some places with large deposits of fine silt to produce several dust storms during the year. This weak dust column is a relatively low pressure circular system that occurs in the center of Saudi Arabia.

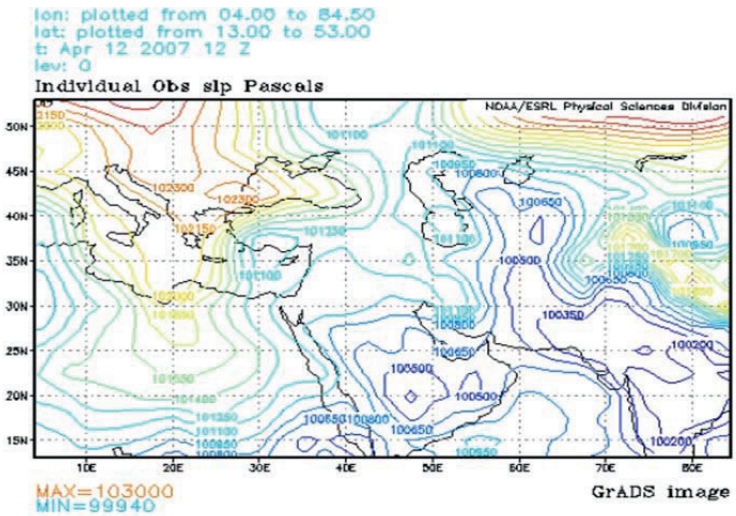

Figure 10. Sea level pressure contours on April 12, 2007

The strongest sand storm in this period occurred on April 12, 2007. Given that the isobaric lines during sand storm are spatially closed and are located directly on the southwestern of Iran (Taghavi and Asadi, 2009), the concentration of dust particles considerably increases in the atmosphere. Increasing the dust concentration, the air quality in transportation routes put at risk and even lead to cancellation of the flights at all airports in the region.

To better understand the dust and sand storm, a number of meteorological variables collected in Ahvaz station such as temperature, pressure, and wind speed were analyzed during the five-day period (April 10-14, 2007). Differences in temperature, pressure, wind direction and visibility for Ahvaz are hourly investigated. These variables can be re-analyzed from the National Center for Environmental Prediction of the National Oceanic and Atmospheric Administration (NCEP-NOAA). Ahvaz is geographically located in 31º 20´ N latitude and 48º 40´ E latitude.

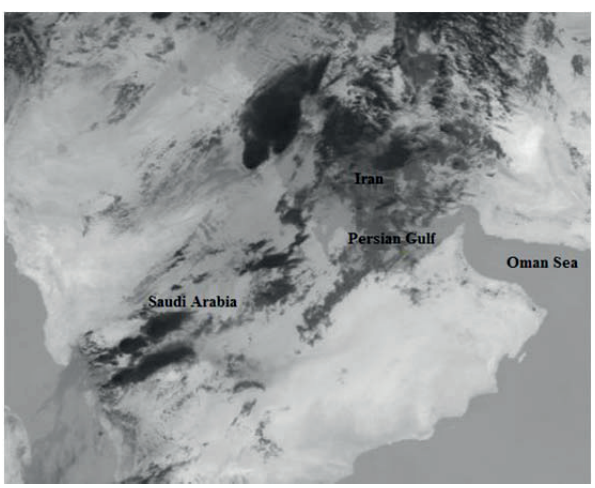

Figure 11. Infrared image from Meteosat5, sand storm on April 12 2007 (dark parts)

Figure 11 shows that the strong winds are in accordance with the spatially closed isobar lines in the east. The wind direction changed suddenly on April 12 and then blew from the west and southwest of the area. This variation represents a cold front storm passing (cyclone) in the area which caused a temperature reduction from 27 ºC to 14 ºC and then rising the sea level pressure (in two days later).

Figure 12 indicates Ahvaz temperature during the dust on April 12, 2007 for a daily cycle of solar heating of the passing fronts along with the low pressure system. Five peak points of temperature are seen in the figure that corresponds to the Z12 of the five-day study. The highest temperature happened at Z11 on April 10 (34ºC), when the strong dust winds brought the warm weather into the city and surroundings. Z10 and Z11 also indicate the maximum wind speed at a speed of 9m/s to 10m/s that blew with the angle of 160-180 degrees from the south and southeast of the region.

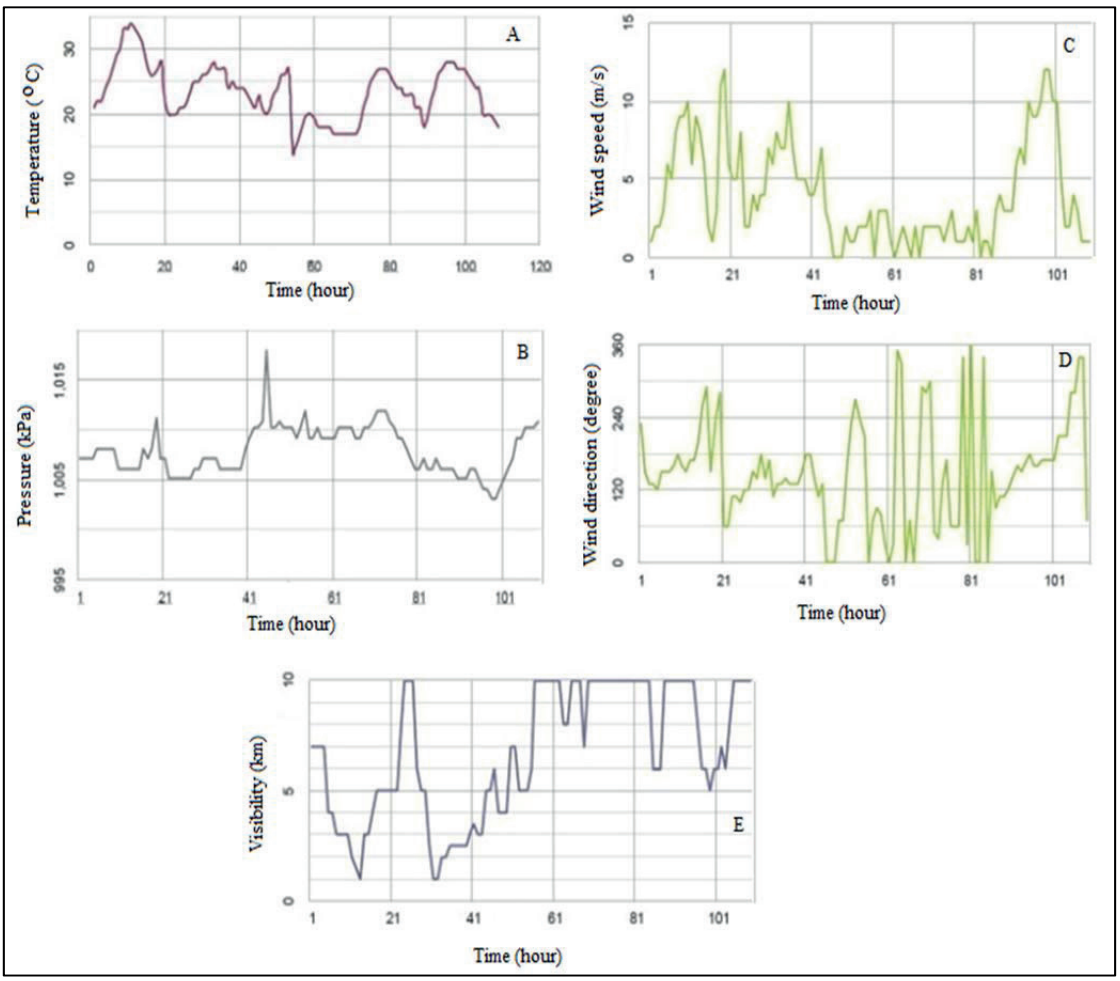

Figure 12. Variations of temperature (A), pressure (B), wind speed (C), wind direction (D), and visibility (E) in Ahvaz station on April 10-14, 2007 (Taghavi and Asadi, 2009)

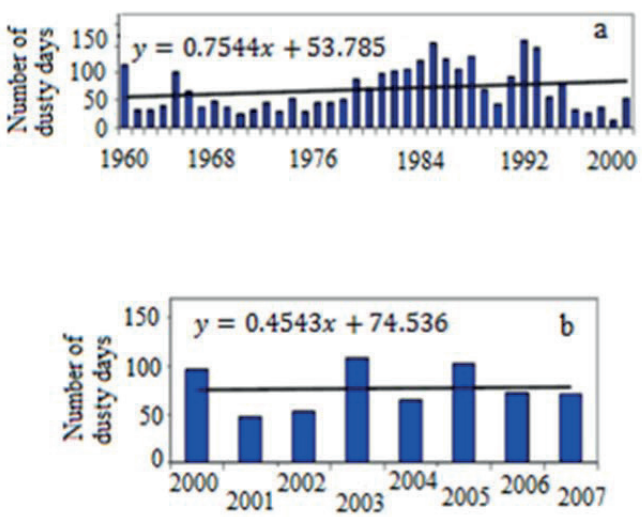

Figure 13. The dust storm frequency in Ahvaz station during 1960-2000 (a), and 2000-2007 (b)

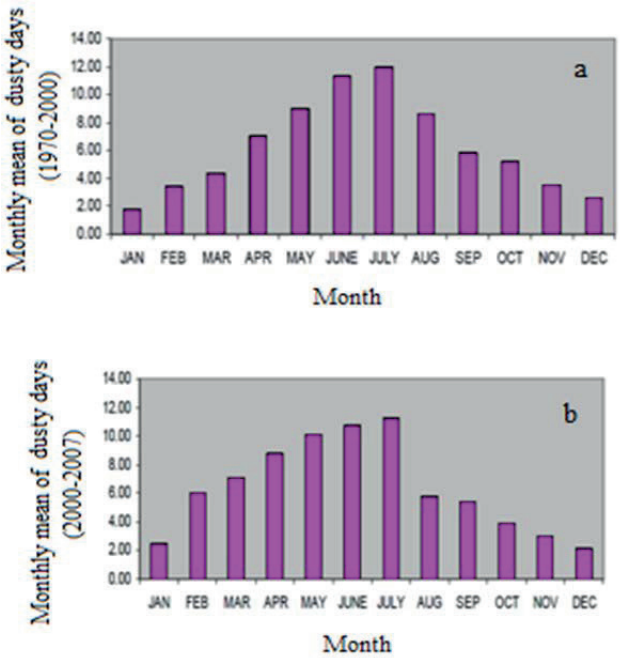

Figure 14. Monthly mean of dusty days in Ahvaz during 1970-2000 (a), and 2000-2007 (b)

Figure 13 indicates the changes of dust storm during the years of 1960- 2007 and analyzing of dust storms' frequency (Chun *et al.*, 2008). The results represent that the dust storm frequency increased during the years which can be related to climate change and global warming among the decades.

In addition, the monthly distribution of the dust storms indicates that the maximum frequency of dusty days were reported for June and July, during 1970-2000; but in 2000-2007, the distributions were in maximum in the months of April to July.

Nowadays, due to the wind blow, considerable amounts of dust are arisen up from desert and semi-arid areas and are deposited at a distance of 5000 to 10,000 kilometers away from these areas over the ocean. Dust rises up to the top of the troposphere where it absorbs heat and prevents the solar radiation. In the upper atmosphere, the effect of dust on the solar radiation is -0.25 Kw/m^2, while its effect on long wave radiation is 0.34 Kw/m^2. Global average of dust storm record at ground level is -0.96 Kw/m^2, this value in dry areas and adjacent to the sea such as the Arabian Peninsula increases to more than 8 Kw/m^2. A result of dust is cool hours of the day compared to the normal day that will lead to reduced convection.

According to the evidence of dust due to industrialization, agricultural development and accelerate in the burning of tropical rainforests in developed countries have caused a global cooling effect. As a result of human activity in the field of agriculture, the massive scale of dust storms occurred in history. In the years from 1951 to 1955, the number of 3882 of dust storms occurred in Central Asia. In Turkmenistan, for a period of 25 years, the 9270 of dust storm have been reported as well.

In April 1928, due to a dust storm more than a million km^2 of steppe area in Ukraine was evacuated and more than 15 million tons of Chernozem eroded and deposited in an area of six km2 in Romania and Poland. The depth of soil erosion in some of the areas was reported 12 to 25 cm (Azizi, 2004). The diameter of dust particles suspended in the air is up to 0.05mm and sometimes it may reach to 0.08mm. In nonlocal sands, the particles are rarely larger than 0.25mm, and those that come from remote places have a diameter smaller than 0.05mm.

Conclusion

Dust storm is a sign of weaknesses in land use management, caused by continuous reactions between humans, water, air, and the earth. In this case, the relationships between the atmosphere, water and air and dust storms and dust and sand transportation mechanisms as well as the regional transportation of dust in the atmosphere were taken into account. The behavior of dust storms in the Persian Gulf was investigated using satellite images and meteorological observations. The synoptic analyses showed that the synoptic-scale dust storms were associated to the cold front and storm activities (cyclones). In such weather conditions, there are high pressure variations and also developed baroclinicity that cause strong winds near the earth's surface. Wind raises up the sand and dust particles to higher levels, then carry them in long distances. The results indicated that the dusty days in the southwestern of Iran had an increasing trend during the years of 1960-2007. In addition, in the satellite images on August 7, 2005, the vast clouds of dust were observed over Iraq, Syria, Kuwait, and the Persian Gulf. Most of the dust storms in the world occur in the north of Africa and the southwest of Asia.

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