

## Dust Storm Monitoring Using HYSPLIT Model and NDDI (Case Study: Southern Cities of Shiraz, Bushehr and Fasa, Iran)

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**ABSTRACT** The occurrence of dust storms and their sources in the southern and central parts of Iran during the period of 2002 to 2009 was investigated. For this purpose, the meteorological and synoptic data, data from the middle and upper atmosphere, and wind flow tracking model were used. Dust storms and NDDI were traced using satellite imagery from Fasa, Shiraz, and Bushehr stations. Analysis of the ground data indicated that one of the strongest storms occurred in 2008 and the most intense dusty day was June 10, 2008. The results of tracing wind flow in the fiercest dusty day using HYSPLIT model indicated that dust masses originated from the western parts of Iraq and eastern Syria and transported by the northwest winds in the region. The results indicated that west winds are caused by the presence of the low pressure air mass in the center of Iran and the high pressure air mass in the northeast of Africa. It is concluded that terrestrial measurements, weather patterns, tracing wind flow model and NDDI index have suitable capability to detect the movement of dust storms.

**Key words:** *Iran, Normalized Dust Difference Index, Wind flow tracing*

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### 1 INTRODUCTION

Dust phenomenon mostly occurs in arid and semi-arid regions and adversely affects human health, economy and natural resources. Dust storms mostly originate in areas that have an extremely dry climate with average annual rainfall of less than 100 mm (Goudie and Middleton, 2001). Dust can act as an agent of climate change by its concentration and vertical distribution in the atmosphere, particle size and

mineralogical characteristics (Xie *et al.*, 2010). The increasing trend of dust storms in recent years has attracted the attention of many researchers worldwide, based on the scope and the widespread effects, including the dust origin, the processes of its progress, transition mechanism, and its impact on the environment (Ekstrom *et al.*, 2004; Ding *et al.*, 2005; Dayan *et al.*, 2008; Gao and Han, 2010).

In Iran, too, as a vulnerable country to

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frequent dust storms, particularly in recent years, several studies covering various aspects of this phenomenon have been conducted. Satellite-synoptic analysis often suggests that the deserts of Iraq, Syria and Saudi are the origin of dust in most cases (Reivandi *et al.*, 2010; Shamsipoor and Safarrad, 2012; Ranjbar Saadatabadi and Azizi, 2012; Azizi *et al.*, 2012; Mousavi *et al.*, 2014; Vali *et al.*, 2014). The Azores High associated with migratory systems of westerly winds is considered the most important synoptic factor affecting on dust systems in the studied area (Farajzadeh and Alizadeh, 2011; Nohegar *et al.*, 2012).

Some studies have also focused on tracing dust storms using satellite imagery and remote sensing techniques (Wang *et al.*, 2011). HYSPLIT model has been used in several studies dealing with dust, including tracing its transport pathways and frequency (McGowan and Clark, 2008; Wang *et al.*, 2011; Vali *et al.*, 2014). Several methods have been developed in

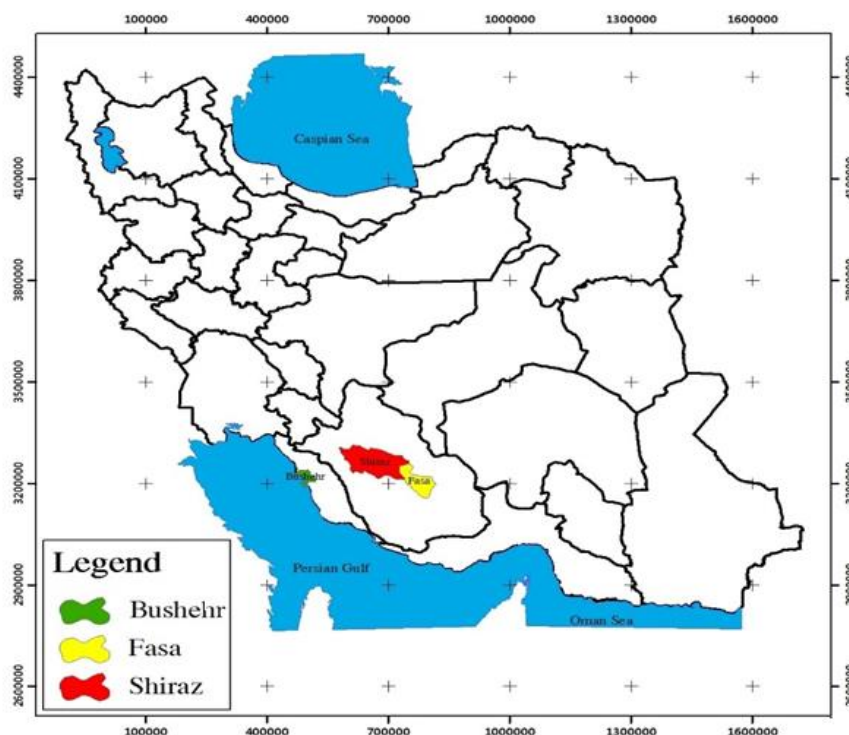
remote sensing and satellite imagery for detecting dust storms, including application of visible and thermal infrared spectrum (Qu *et al.*, 2006).

The goal of this study was to investigate the characteristics of one of the most extreme dust storms in recent years in Shiraz, Bushehr and Fasa synoptic stations. Climatic conditions and atmospheric systems leading to dust phenomenon was studied and, finally, the main source of dust storms was studied by tracing the model of wind flow and NDDI index.

## 2 MATERIALS AND METHODS

### 2.1 Study area

Three synoptic stations in three dust-storm-affected cities were considered in this study (Figure 1), including Shiraz ( $29^{\circ}32'$  and  $52^{\circ}36'$  N, 1484 MASL), Bushehr ( $28^{\circ}59'$  and  $50^{\circ}50'$  N, 19.6 MASL), and Fasa ( $28^{\circ}58'$  and  $53^{\circ}41'$  N, 1288 MASL).



**Figure 1** The geographical location of the studied stations

## 2.2 Methods

In the first step, one of the dust storm events with a considerable intensity and duration was selected by reviewing Iran Meteorological Organization data in Shiraz, Bushehr and Fasa synoptic stations during the years of 2000 to 2009. This event occurred from 8 to 30 June, 2008. Then, visibility, wind speed and direction, relative humidity and rainfall were measured for each day. For synoptic analysis, the middle and upper atmospheric data, such as sea level pressure, geopotential height of 500 hPa, wind direction, vertical velocity, surface temperature, and subtropical wind profiles from 1000 to 100 hPa height were received from the NCEP/NCAR dataset and were drawn using GRADS software in 0 to 80 E degrees longitude and 10 to 70 N degrees latitude. Air parcel tracing model (HYSPLIT) was used to determine the dust storms path. The air parcel tracing model (as packages carrying dust particles) in the areas involved with this phenomenon was performed at the time of maximum dust intensity in weather stations by backward and forward movement in the model (HYSPLIT). Dust storms source routing has been used from 3 satellite images of MODIS sensor which cover west of Iran, Iraq and east of Syria at the peak of this phenomenon. Finally, the NDDI index was used for dust storm source routing. Measurements of other ground-based parameters, such as visibility are helpful for better dust extraction from remote sensing images. In fact, having prior knowledge on the environment helps to better interpret dust storms (Jokar *et al.*, 2009). The NDDI can be written as equation (1).

$$NDDI = \frac{b_7 - b_3}{b_7 + b_3} \quad (1)$$

where, B3 and B7 are the third (0.469  $\mu\text{m}$ ) and seventh (2.13  $\mu\text{m}$ ) reflection bands of Modis sensors, respectively. The image of NDDI index was provided using this formula and used for subsequent analysis. Values of NDDI index are

negative for the clouds and less than for the dust in other parts of the ground; therefore, we can recognize dust from water, clouds and other things by taking 0.26 for the threshold value of this indicator (Li *et al.*, 2002).

## 2.3 Remote sensing data

The data used for this study include 3 images of June 8 to 10, 2008 from Modis sensor combining Terra and Aqua satellite imagery.

## 3 RESULTS

### 3.1 Statistical evaluations of dust phenomenon in the studied area

The present weather codes (WW) of Iran Meteorological Organization in the south part of Iran during 2000-2009 revealed that one of the strongest events of dust storms occurred in June 8-30, 2008 in Shiraz, Bushehr and Fasa stations. Wind variation diagram during that period at three stations showed that Bushehr station had the greatest range of velocity (Figure 2), which is confirmed by visibility diagram in this station (Figure 3).

### 3.2 Synoptic patterns causing and carrying dust storm

The geopotential elevation map of 500 hPa shows an Azores high pressure on Saudi Arabia and East Africa with the central balance of 5950 geopotential meters, a strong low pressure in Syria with central balance of 5700 geopotential meter and another low pressure over the west of India and the south of Oman Sea with central level of 5800 geopotential meter (Figures 4 & 6). The map of sea level pressure showed that there was a strong high pressure condition over Europe and north of Black Sea which extends to the northeast of Africa. There was another high-pressure system in the north of Aral Sea and the Caspian Sea with the central flow to 1020 hPa. On the other hand, a low pressure system was present with three different kernels in the east of Iran, the north of Pakistan and the south of Oman Sea with a central flow to 996 hPa (Figures 5 & 6).

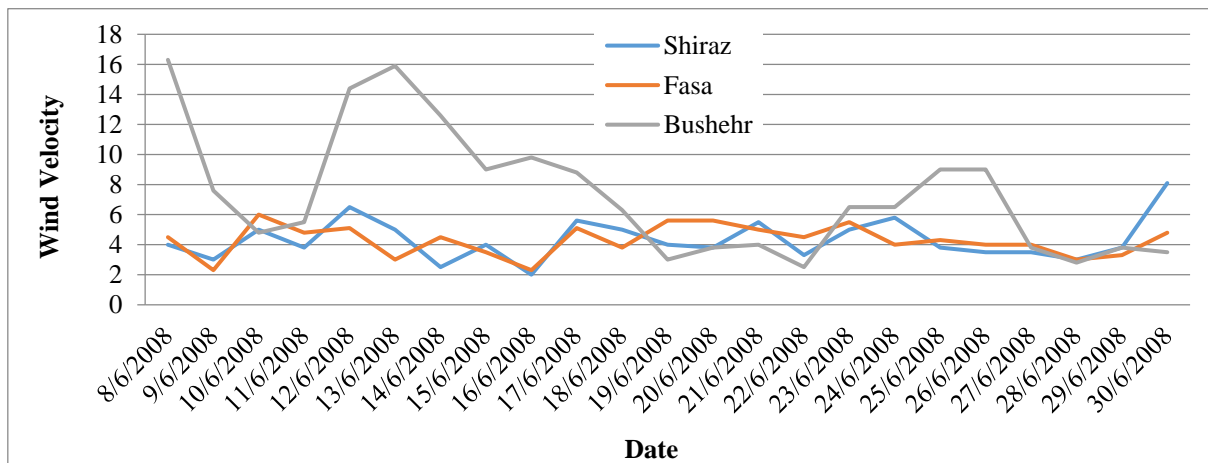


Figure 2 Wind velocity variations diagram during the stormy days

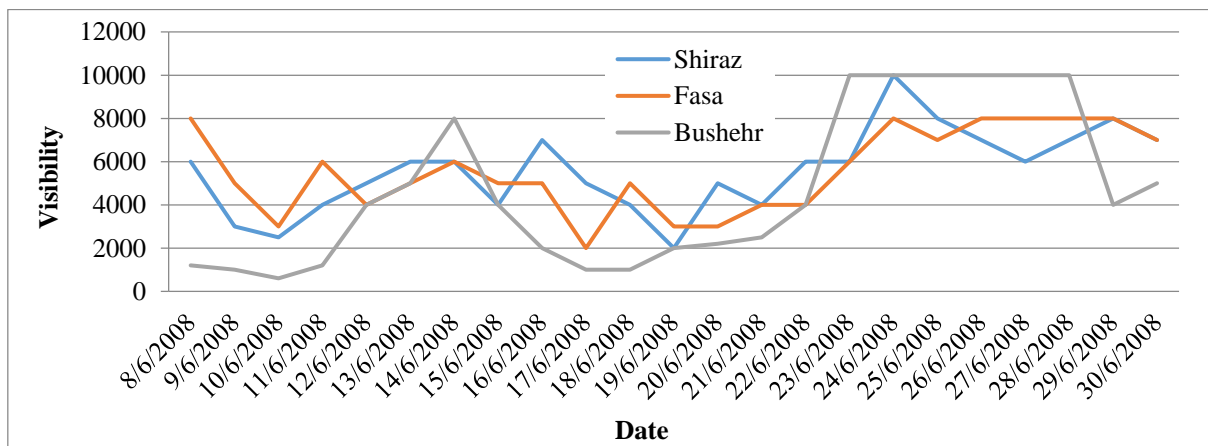


Figure 3 Visibility variations diagram during the stormy days.

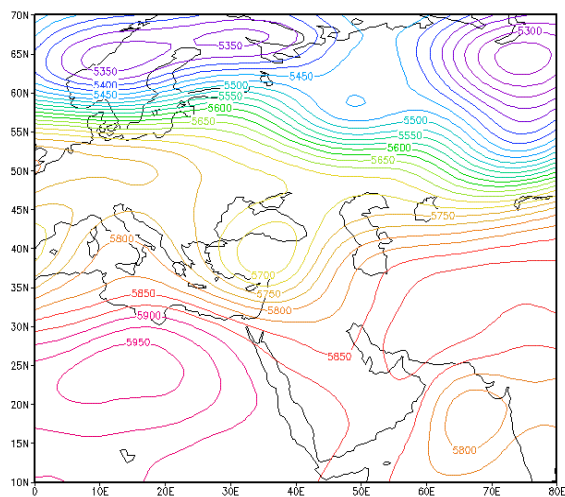


Figure 4 Pressure level map of 500 hPa on June 10, 2008

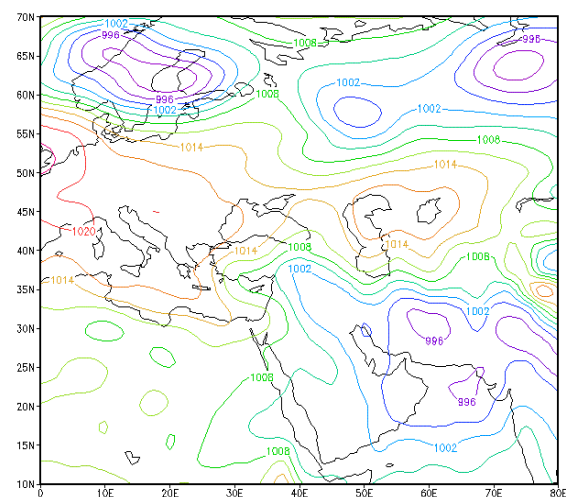
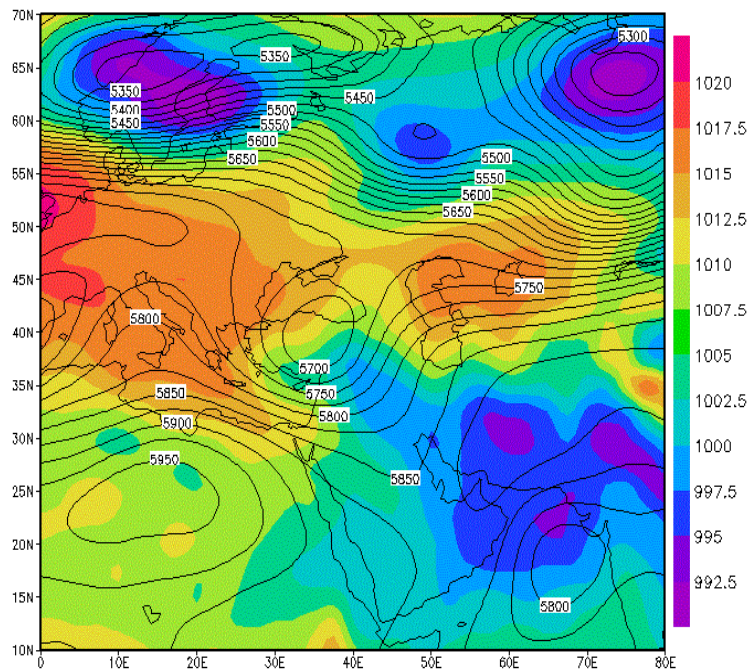


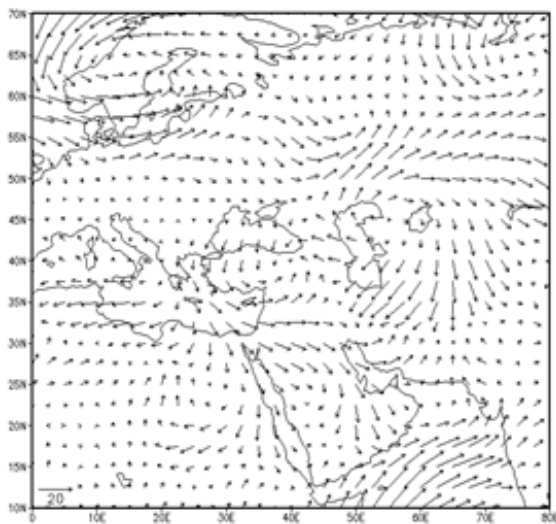
Figure 5 Sea level pressure map of 500 hPa on June 10, 2008



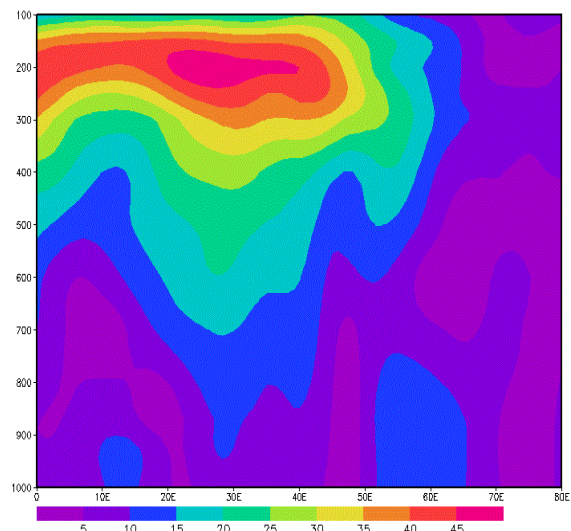
**Figure 6** The mixed map of pressure level of 500 hPa (Contour Line) and sea level pressure (color range) on June 10, 2008

The wind map of sea level showed the dominance of west and northwest winds in the area which passed from north of Saudi Arabia, Turkey and Iraq (Figure 7). Subtropical wind profile is indicative of the nucleation above 400

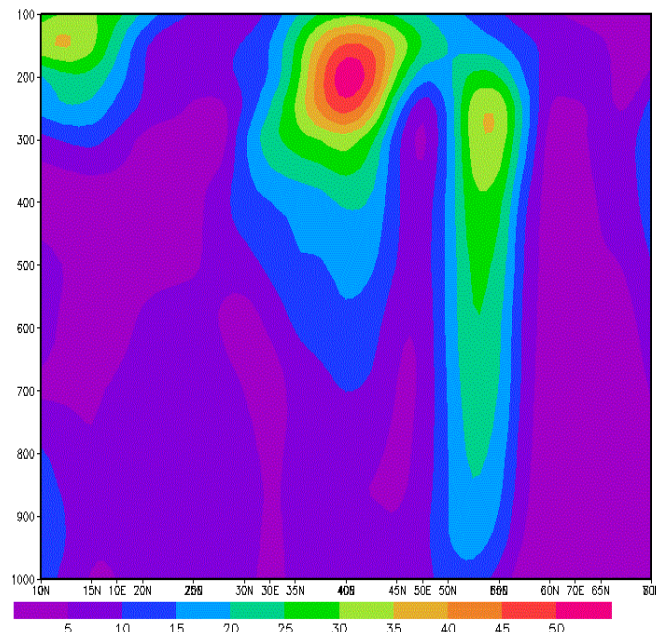
hPa and its maximum level between 100 and 300 hPa. Its sequences reached to ground in the latitude of 25° to 45° and longitude of 45° to 65° (Figures 8 & 9).



**Figure 7** The wind vector map in sea level on June 10, 2008



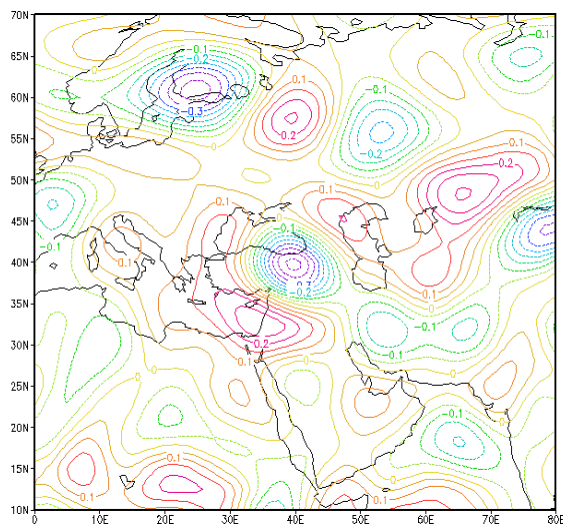
**Figure 8** Subtropical wind profile in the longitude of 50 o°n June 10, 2008



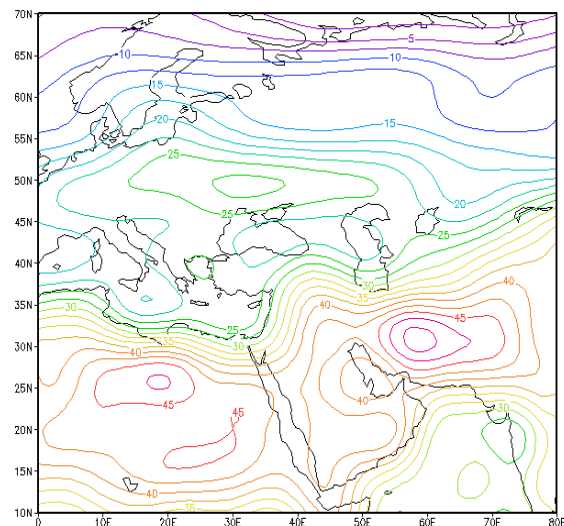
**Figure 9** Subtropical wind profile in the latitude of 30° on June 10, 2008

Vertical wind velocity map also has a central contour of -0.1 in the central regions of Iran that shows a downward air flow in the area. There is also a core of upward flow with central contour of 0.2 in northern Saudi Arabia, Iraq and Syria that shows an upward air flow in these areas (Figure 10). The isothermal maps of sea level

indicate the dominance of 50° curve in the center of Iran and the dominance of 42.5° curve in the east of Saudi Arabia. In addition, the 40° curves have dominated in Iraq and Syria which increase air temperatures and drought in the region (Figure 11).

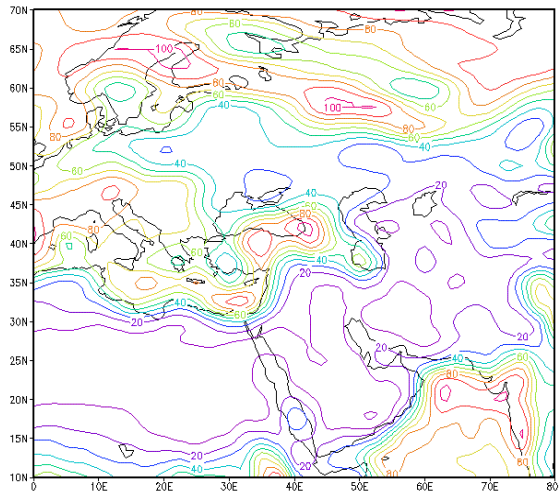


**Figure 10** Vertical velocity map at sea level on June 10, 2008



**Figure 11** Isothermal map at sea level on June 10, 2008

The patterns related to the region moisture content show relative humidity of 10% in Iran, Saudi Arabia, Iraq and Syria (Figure 12). Special humidity content was very low and was equal to

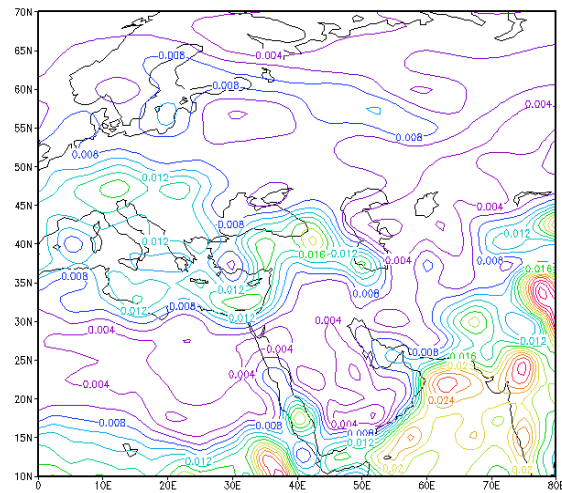


**Figure 12** Relative humidity map at sea level on June 10, 2008

### 3.3 Modelling the transport of dust particles

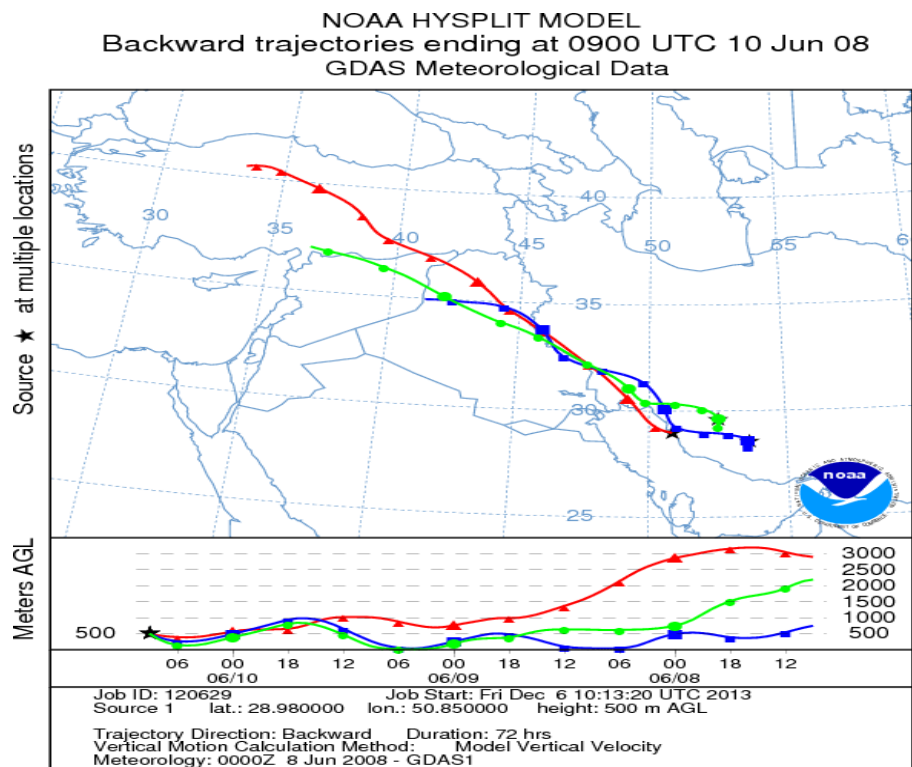
Considering the severe reduction in visibility on June 10, 2008, tracing of wind parcels was performed using wind flow tracing model and backward and forward trajectory methods on this day. The tracing of wind flow by backward trajectory method began from Shiraz, Bushehr and Fasa at 9 am on June 10, 2008 and continued with going backward to 72 hours. Most south and southwest parts of Iran are affected by air parcels that are originated from the northwest of Iraq and east of Syria at that time (Figure 14). Hence, dust masses can originate from the west of Iraq and the east of Syria by the northwest-southeast wind direction of the region. Wind flow tracing by Forward Trajectory method also began from Shiraz, Bushehr and Fasa at 5.30 am UTC on June 10, 2008 and continued with going forward to 72 hours, which indicated that the air parcels associated with dust masses would reach to the center and north of Iran after passing through the southwest regions (Figure 15). In the

the contour amount of 0.004 in Iran, Saudi Arabia, Iraq and Syria (Figure 13). These also represent the minimum humidity and very high drought which can cause or aggravate the dust.

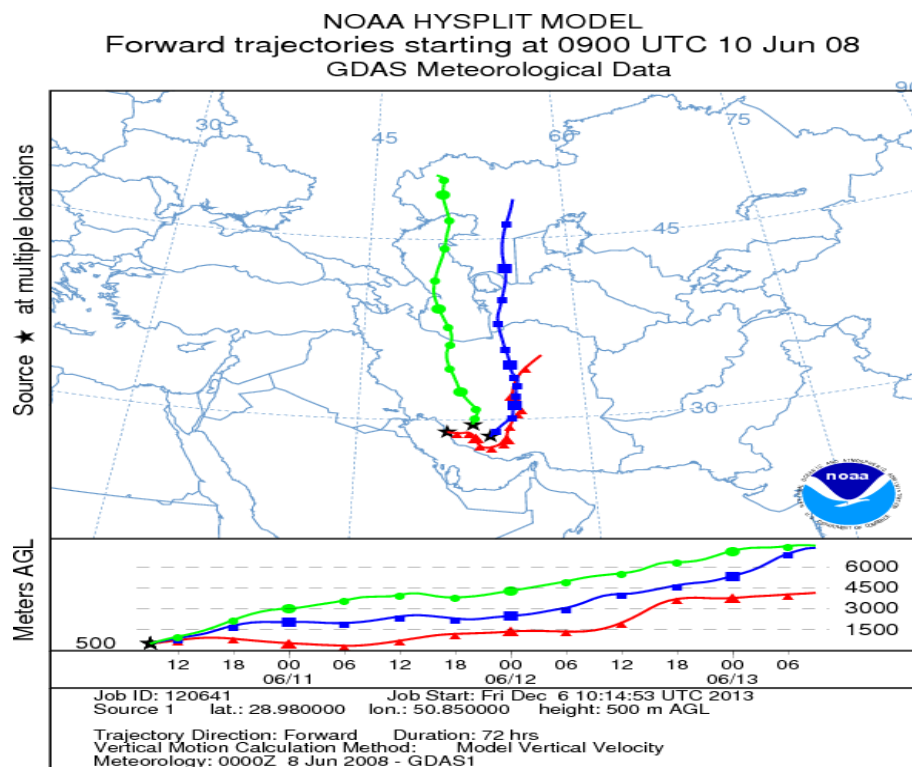


**Figure 13** Special humidity map at sea level on June 10, 2008

output model maps, each point in the paths terminating to the station which may be square, triangle or circle based on the output of the model and the model type represents the beginning of a 6-hours period and the next point represents the end of it. Asterisk in the output of the model indicates the dust stations and their longitude and latitude are given to the model. Wind direction is shown with green, blue and red colors, which is referred to Shiraz, Fasa and Bushehr, respectively. The displayed altitude at the bottom of each map represents the path elevation from the ground surface in the stations. If the air parcels are passed from the productive zones of dust masses, it can be identified as the dust mass passageway. In this study, it was tried to investigate only the mass and focal points of dust in which the wind tracing route has led to dust storm. It is shown that the dust of the region is originated from the northwest of Iraq and east of Syria (Figure 14), and wind parcels go through the center and north of Iran (Figure 15).



**Figure 14** The backward wind flow tracing on June 10, 2008



**Figure 15** The forward wind flow tracing on June 10, 2008



### 3.4 Dust storms tracing using satellite imagery

After tracing the wind flow, three images of dusty days were prepared from the NDDI index in order to trace dust storms using the satellite images of MODIS (Figures 16-18). The image of June 8 indicates which dust storms have been formed from Iraq and Saudi Arabia, and the development and entry of storm to Iran can be seen on June 9. On June 10, the focus of storms

was on the southwest of Iran and the studied region and would continue moving to the east with reduced visibility in the area. On June 10, which was specified as the fiercest dust storm in Shiraz, Bushehr and Fasa, the storm was completely settled in the area and going toward the central and eastern regions. Therefore, the movement of dust storms can be monitored and predicted.

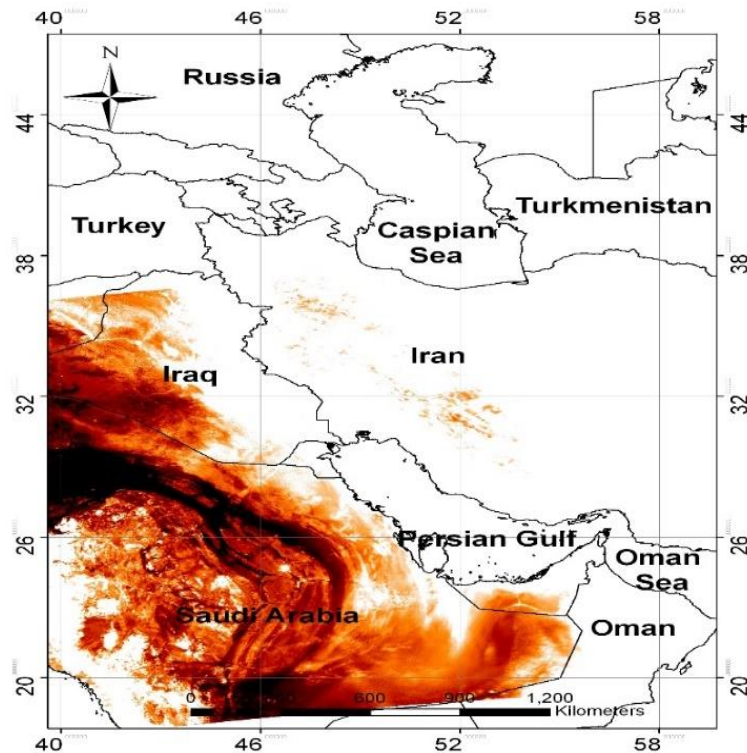


Figure 16 The image of NDDI index on June 10, 2008

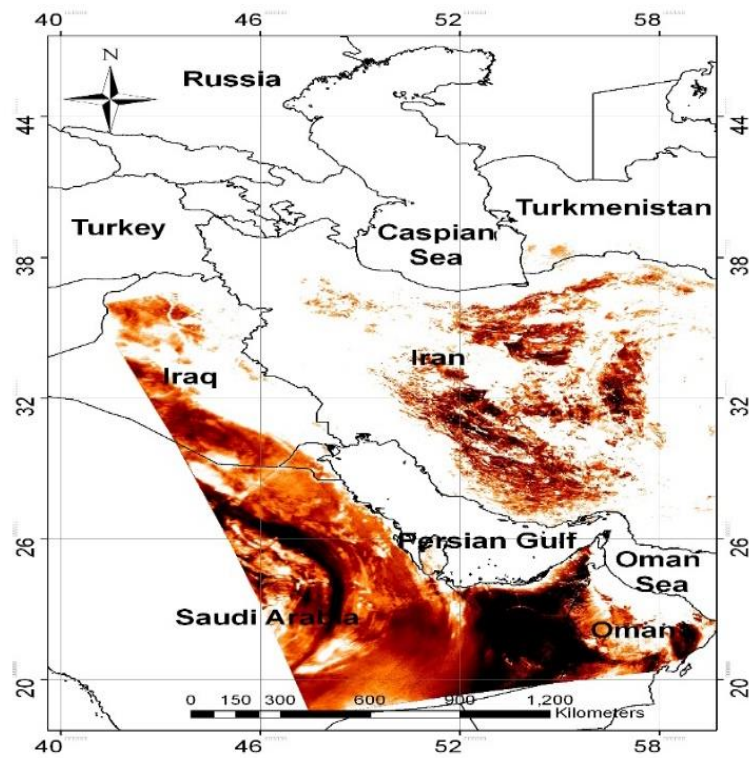


Figure 17 The image of NDDI index on June 10, 2008

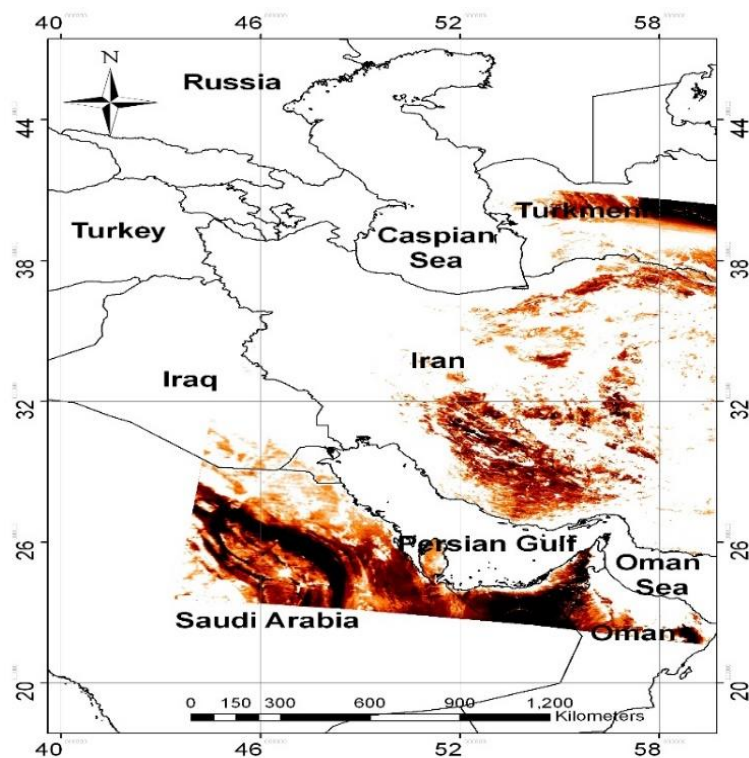


Figure 18 The image of NDDI index on June 10, 2008

#### 4 DISCUSSION

Considering the large-scale nature of dust storms, they require a comprehensive review to determine not only the factors affecting their rise, but also recognize their origins which can eventually lead to reducing their impacts. The storm in this study, as one of the strongest dust storms in recent years, could provide an appropriate understanding of weather patterns leading to this phenomenon and tracing winds containing dust particles. Studying the weather patterns during the storm days showed that the Azores High on Saudi Arabia and east Africa, strong low pressure in Syria, west and northwest winds passing through northern Saudi Arabia and Iraq created a dust system in the area. The kernel of the upward movement in Iraq, Syria and north of Saudi Arabia represents the ascending movements. The wind vertical velocity map showed a downward airflow in the studied stations which is the cause of rising temperature and drought in the center of Iran, Iraq and Syria with the curves of 50 and 40 in the isothermal map, respectively. Special humidity is very low and is equal to contour amount of 0.004 in Iran, Saudi Arabia, Iraq and Syria. These also represent the minimum humidity and very high drought which can cause or aggravate the dust. The association between these conditions and the atmospheric circulation systems have been found to be the cause of increasing drought and creation or strengthening of dust storms in the in the area (Zolfaghari and Abedzadeh, 2005; Tavoosi *et al.*, 2010; Khoshhal *et al.*, 2012; Mousavi *et al.*, 2014). The origin of dust in Iran is from the Syrian Desert (near the western border of Iraq) and Iraq (Mosul region to Bahrolmah) (Zolfaghari and Abedzadeh, 2005; Ataei and Ahmadi, 2010). The results of tracing the route of winds carrying dust by the HYSPLIT model revealed that the main source of dust in the studied area was the northwest of Iraq and east Syria. These results correspond with the earlier studies (Shamsipoor

and Safarrad, 2012; Azizi *et al.*, 2012; Ranjbar and Azizi, 2012; Mousavi *et al.*, 2014).

Through analyzing similar cases of dust in the region, similar conditions leading to such kind of storm occurrence can be recognized, so that preventive measures to reduce impacts can be taken. Source routing of dust storms can be performed with greater certainty by investigating more cases in this scale. Wind flow tracing and the use of NDDI index in the investigation of the dust storm on June 10, 2008 showed that the imported dust to the west of Iran were originated from the west of Iraq and the east of Syria, which had also been found as the main focus of imported dusts to Iran by Darvishi (2011).

#### 5 CONCLUSION

A combination of satellite data from Terra and Aqua was used for monitoring, analysis and tracing of dust storm that occurred on June 10, 2008. According to this detection technique, multiple time, spatial data, and radiometric satellite images provided the best result for the distinction of methods and selecting a reliable one to predict the possible future events resulting from dust. The results indicated that application of the NDDI index, the wind and dust tracing methods can be helpful in monitoring the dust storms. Simultaneous use of terrestrial measurements, weather patterns, tracing wind flow model, and NDD index were found to have a suitable capability to detect the movement of dust storms. Long-term monitoring of the storms with due consideration to the topography and soil conditions and using thermal bands of satellite images can help us to achieve a more comprehensive model for predicting future storms.

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**پایش طوفان‌های گرد و غبار با استفاده از مدل HYSPLIT و شاخص NDDI****(مطالعه‌ی موردی: شهرهای شیراز، بوشهر و فسا)**سجاد خاموشی<sup>۱</sup>، فاطمه پناهی<sup>۲</sup>، عباسعلی ولی<sup>۳</sup> و سید حجت موسوی<sup>۴</sup>

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چکیده طوفان گرد و غبار در نواحی جنوبی و مرکز ایران در بازه زمانی ۲۰۰۲ تا ۲۰۰۹ با استفاده از داده‌های هواشناسی، داده‌های سینوپتیکی جو میانه و بالا، مدل رهگیری جریان باد جهت شناسایی مناطق منشا و ردیابی طوفان‌های گرد و غبار و شاخص NDDI جهت رهگیری طوفان‌های گرد و غبار با استفاده از تصاویر ماهواره‌ای در ایستگاه‌های شیراز، فسا و بوشهر بررسی شد. بررسی داده‌های پایگاه گردشی زمینی نشان می‌دهد که سال ۲۰۰۸ دارای یکی از شدیدترین طوفان‌های گردوغبار در بازه مطالعاتی بوده، به طوری که روز ۱۰ ژوئن ۲۰۰۸ با میدان دید کمتر از ۵۰۰ متر شدیدترین روز گردوغباری ایستگاه‌های مطالعاتی می‌باشد. نتایج رهگیری جریان باد با استفاده از مدل HYSPLIT در شدیدترین روز گرد و غبار نشان می‌دهد که این توده‌ی گرد و غبار نشأت‌گرفته از مناطق شمال غرب عراق و شرق سوریه بوده و با جهتی شمال غربی - جنوب شرقی وارد ایران شده بود. نتایج نشان می‌دهد که با حاکمیت یک مرکز کم فشار قوی در شرق ایران و پرفشار در شمال آفریقا، بادهای غربی ایجاد شده و باعث ورود گرد و غبار حداکثری به منطقه شده، همچنین مسیر طوفان‌های گرد و غبار ورودی به غرب ایران، از شمال غرب عراق و شرق سوریه می‌باشد. در مجموع نتایج این پژوهش بیانگر این مطلب است که استفاده همزمان از اندازه‌گیری‌های زمینی، الگوهای جوی، مدل رهگیری جریان باد و شاخص NDDI قابلیت مناسبی جهت تشخیص مسیر حرکت طوفان‌های گرد و غبار را دارا می‌باشد.

**کلمات کلیدی:** ایران، رهگیری جریان باد، شاخص NDDI