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Identification of the synoptic patterns of dust storms over southern provinces of Iran

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Abstract

The present study was conducted to identify the synoptic patterns that could display the origin of dust-storm over southern provinces of Iran. In order to design these patterns, we selected 17 weather stations whose data-sets of visibility per meter for one decade (2000 to 2009) were provided from Meteorological Organization of Iran. This paper used daily data of Sea Level Pressure (SLP) from NCEP/NCAR for designing the synoptic patterns as composite maps for each group. The extraction of dust records from the stations and consequently the evaluation of dust-storms frequency were our primitive aims. According to results, there were totally 345 dust-storms from 2000 to 2009 in the study area. Moreover, our results revealed that the dust-storms could be classified to three groups, including pervasive, semi-pervasive, and small ones based on Dust Stations (DS) frequency. All the dust-storms comprise 2 to 41 days. This paper illustrated the patterns for all the peak dusty days of the above-mentioned groups by extracting the sea level pressure data. According to the findings, the synoptic patterns demonstrated that the Pakistan Low is an important thermal low in Southern Asia, which pumped dust from 5 routes originated from Sahel, Southern Hijaz, and Mesopotamia Plain, toward the study area, particularly during the pervasive ones. This low appeared weak and disappeared during semi-pervasive and small dust-storms.

Keywords*:* Dust-storms; Middle East; Pressure systems; Synoptic analysis; Iran

1. Introduction

Asian dusts are highly associated with those of global circulation (Shao and Dong, 2006). Dust particles are suspended at high altitude in the atmosphere. This altitude ranges from 2500 meters (Levin *et al*., 2005) to 4000 meters and even 8000 meters (Han *et al*., 2015). Subsequently, the distribution patterns of pressure systems highly affect dust-storms. There are multiple researches about the synoptic factors of dust-storms. For instance, Liu *et al*. (2006) stated that the high pressure in northern China causes dust storms in Taiwan, a deep trough resulted in blowing dust and dust-storm over Southern Mongolia (Sun *et al*., 2006); the trough and the associated cold front were ended dust over New Zealand (McTainsh, 2005); the biggest amount of dust occurs during winter generated by strong regional pressure gradients (Godon and Todhunter, 1998). Thhhese were some examples of the relevant researches.

According to Alijani's investigation (Alijani, 2001), rain is predictable once an adequate moisture is along with baroclinic atmospheric conditions in Iran. Otherwise, dust storm is anticipated (Fattahi *et al*., 2012). Thus, the synoptic analysis of pressure systems could determine the sources of dust storms. Silt (Goudie, 2014) or the composite of silt and clay are known as the components of dust storms.

The appearance of different allergic discomforts in people (Shakurnia, 2013), the increasing rate of cardiac and blood vessels (Fathnya *et al*., 2012), the penetration of particles less than 2.5 micro-meters in depth of lungs (Tsai, and Chen, 2006), and the major problems in the utilization of micro-wave bands for terrestrial and space communication (Abuhdima and Saleh, 2011) are the harmful

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effects of dust storms. However, the procurance of nuclei aerosols for rain (Liu *et al*., 2006), nutrients minerals such as potassium at surface water of the oceans (Goudie and Middleton, 2001), and aluminum, iron, and potassium (Shahsavani *et al*., 2011) in soils could be considered as their advantages.

The increase in dust emissions in deserts during last decades (Engelstaedter *et al*., 2006) could be an important alarm to Iran that is located on a dry and warm world belt. Some years ago, the dusty storms mostly occurred during spring and summer whereas currently, they occur all year long in Iran (Shakurnia *et al*., 2013). According to the results of dust storms in Sistan, the maximum frequency of them was found to be in June and July, which resulted into a damage of US$ 99.190 million during 2000-2005 (Pahlavanravi *et al*., 2012). Currently, dust-prone areas are not only concentrated in the central Iran, but also in the west, southwest and centeral provinces, such as Tehran, Isfahan and Fars.

Therefore, we conducted the present investigation in order to test the first hypothesis concerning the regularity of the frequency of dust storms in southern privinces of Iran. Then the second hypothesis included the design of synoptic patterns regarding certain exterior dust storm-triggering atmospheric systems.

2. Materials and Methods

2.1 The Study Area

South and southeastern Iran comprise important dust-prone lands.The study area included all the southern provinces of Iran, including Khoozestan, Boosher, Hormozgan, and Sistan. We did not take Kerman Province into consideration since several reaserchers have been carried out on central Iran (Omidvar and Ebrahimi, 2012; Barati *et al*, 2014). Figure (1) and Table (1) represent the study area, our selected weather stations, and the base map of the synoptic patterns.

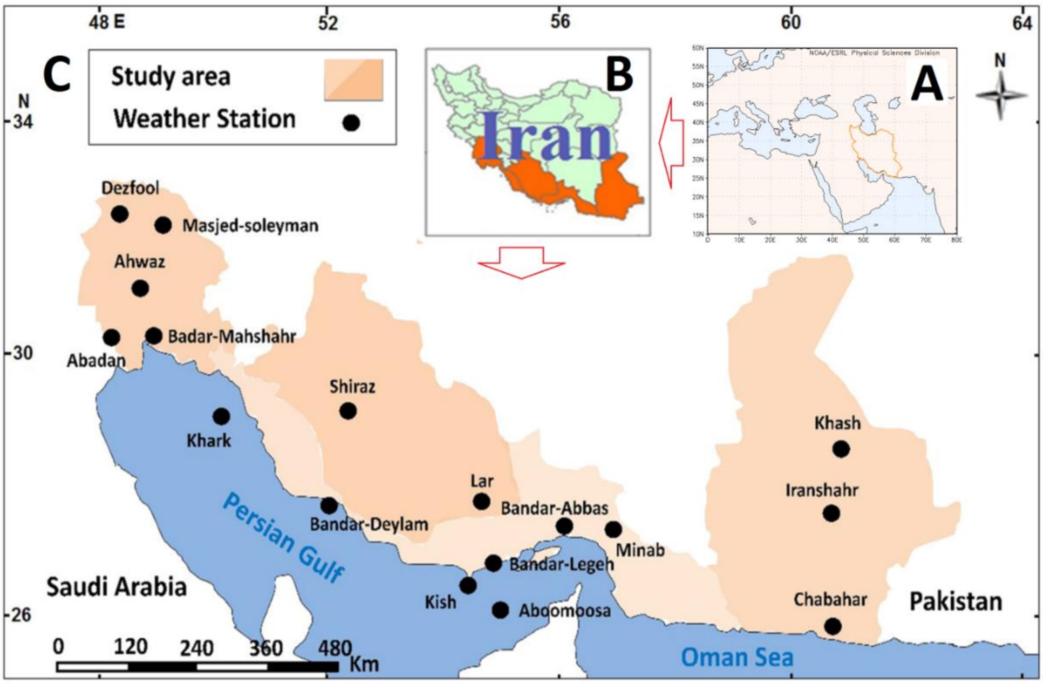

Fig. 1. Base map for the synoptic patterns (A), the location of the study area in Iran (B) and the distribution of weather stations (C)

2.2 Data and methods

We filtered 17 weather stations in southern coastal provinces of Iran, which had the required data from 2000 to 2009.

In this research, the weather station with dust record was addressed to as Dusty Station (DS). Table (1) depicts these stations and their characteristics. We extracted the dataset of visibility per meter with the meteorological code of 06 in the data at 15 p.m. accordimg to local time.

According to Godon and Todhunter *et al*.(1998), who studied dust storms in Red Valley over Northern Dakota, about (70%) of dust storms happened between 12 and 06 PM. at afternoons and their peak frequency was at 3PM. (Fig. 2).

Table 1. Geographical characteristics of weather stations

Row	Station	Lat	Lon	Height (m)A.S.L
1	Dezfool	32◦20'	48◦30'	140
2	Masjed-soleyman	31◦55'	49◦18'	372
3	Ahwaz	31◦20'	48◦40'	10
4	Bandar-Mahshahr	30◦35'	49◦10'	3
5	Abadan	30◦ 22'	48◦ 22'	140
6	Bandar-Deylam	30◦05'	50◦10'	10
7	Shiraz	29◦ 39'	52◦ 35'	1519
8	Khark	29◦ 15'	50◦ 20'	3
9	Khash	28°15'	61°15'	1410
10	Lar	27°40'	54°14'	806
11	Iranshahr	27°15'	61°56'	591
12	Bandar-Abbas	27°15'	56°15'	9
13	Minab	27◦ 13'	57◦ 08'	16
14	Bandar-Lengeh	26°35'	54°58'	11
15	Kish	26◦ 29'	53◦ 53'	32
16	Aboomoosa	25◦ 87'	55◦ 03'	46
17	Chabahar	25◦ 17'	60◦ 37'	11

Source: Iran Meteorological Organization

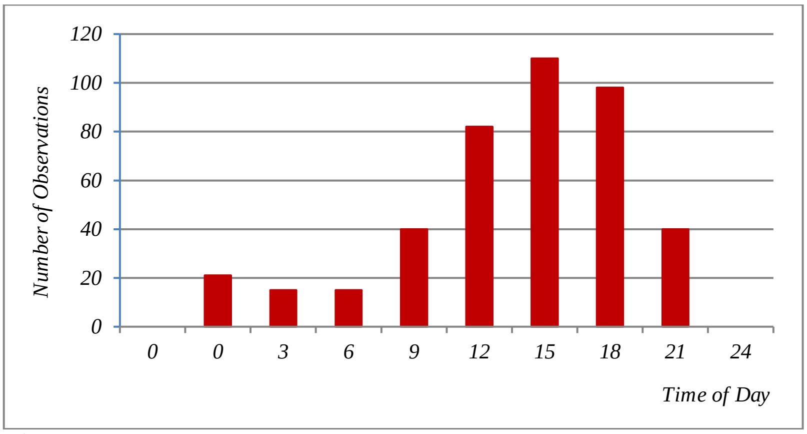

Fig. 2. Frequency of airborne dust observations per 3-houry interval at Fargo, North Dakota, 1948-1994 (Godon and Todhunter *et al*.1998: 32)

Furthermore, Jamalizadeh *et al*. (2008) determined the peak time of dust storms in Zabol area in southeastern Iran from 3 to 6 p.m. They believed that convectional process reached its peak in boundary layer during afternoon. Therefore the UTC of 12.00 o'clock, which was equal to that of 3:30 p.m. (local time), was taken as the monitoring time of the visibility data. The table of daily visibility was prepared for all the 12 months. Table (2) represents one example that stations were arranged in a descending order based on their latitudes.

Table 2. The sample of daily visibility per kilometer during final days of May and first half days of June at 2003 over the southern provinces of Iran

Days Cities	May		Jun													
	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dezfool	7	4	3	4	6									7	6	4.5
Masjed-Soleyman			6	4	6											
Ahwaz		6	5	5	6											
Badar-Mahshahr				8												
Abadan				6	8											8
Bandar-Deylam	5	7	7	5	5									5		
Shiraz		6	3	4	3	5	5									7
Khark																
Khash	0.3	4	8		7				2	8						
Lar			6	5	6	7	7									
Iranshahr	1.2		6	6		7	7		5	6			6	8		7
Bandar-Abbas	6	6	7	4	3.5	4	4	4.5	5	7	6	5	4	6		7
Minab	6	6	8	8	8	7	7	7	7		7	7	7			
Bandar-Legeh		5	5	4	4	5		5	6	8		5	4	5	7	7
Kish	7		4	5	4	5	5	6	6			4	5	4	4	
Aboomoosa				6									8	6		8
Chabahar							8									
Average	4.6	5.5	5.7	5.3	5.5	5.7	6.1	5.6	5.2	7.25	6.5	5.25	5.7	5.9	5.7	6.9

All the 120 tables enabled us primarily, to determine all the DSs, secondly, to recognize their daily frequencies, and thirdly, to draw the monthly graphs of DS frequency changes. Figure (3) depicts one sample of the mentioned graphs related to December 2008. We identified the days with the maximum frequences as one "dust storm event"between the two minimum frequencies of DSs, then the days with the maximum frequencies of DSs account as the peak day of the dust wave. According to Figure (3), we can monitor three events or waves in which the peak day of every dust storm event is illustated with a red triangle.

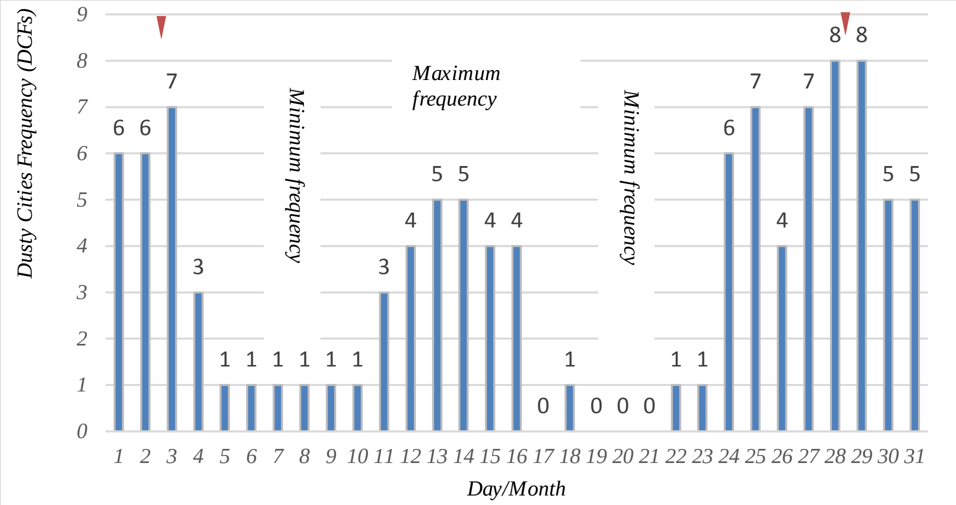

Fig. 3. The daily frequency of DSs and dust storm determination (sample of December 2008) of the southern provinces of Iran

Finally, 120 monthly graphs were illustrated as in Figure 3. These graphs determined 345 dust storms. In the next stage, we designed a staircase graph, including 15 stairs, which exhibits a descending sort of 345 dusts based on DSs in the peak days (Fig.4).

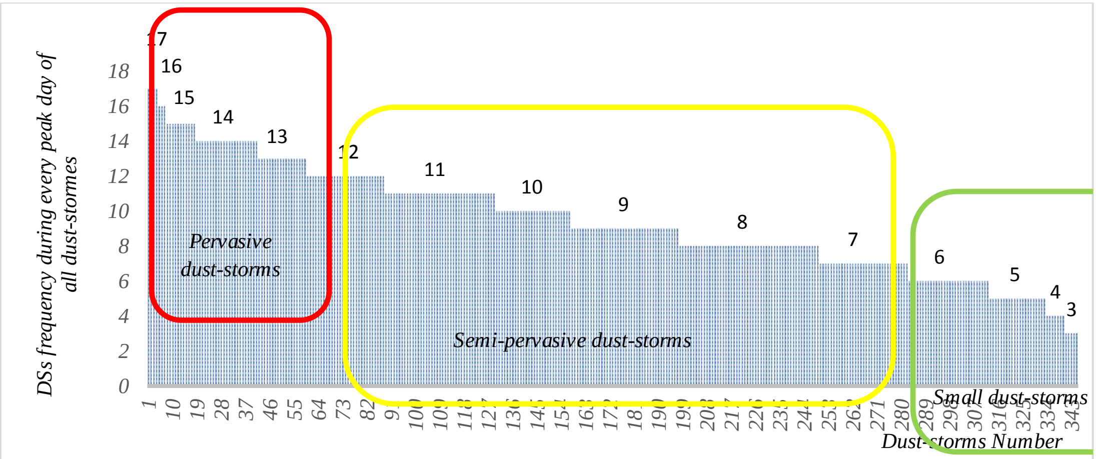

Fig. 4. Descending frequency of DSs during all the days of all the 345 dust storms (2000-2009) of the southern provinces of Iran

We found two footpaces greater than the others and as a result, we could divide all the stairs into three groups, including pervasive, semi-pervasive, and small dust storms:

1) Pervasive dust storms include five groups with 13, 14, 15, 16, and 17 DSs during their peak days.

2) Semi-pervasive dust storms involve five groups with 8, 9, 10, 11, and 12 DSs during their peak days.

3) Small dust storms comprise five groups with 3, 4, 5, 6, and 7 DSs during their peak days.

In the final stage, we employed the daily datasets of Sea Level Pressure (SLP) from NCEP/NCAR for all the DSs for each group separately.

We designed composite maps for each group which were our synoptic patterns in the framework of base-map (Fig. 1-A). They showed the relation between extremely dusty days in the southern provinces of Iran and the location of pressure systems around them. Every composite map, such as Figure 6, is the average pressure pattern corresponding to 15 storm levels categorized during several and non-consecutive days.

3. Results and Discussion

Primitive results indicated that there were totally 345 dust storms from 2000 to 2009 in southern provinces of Iran. We found that the storm frequency have gradually increased during recent decades (Fig. 5).

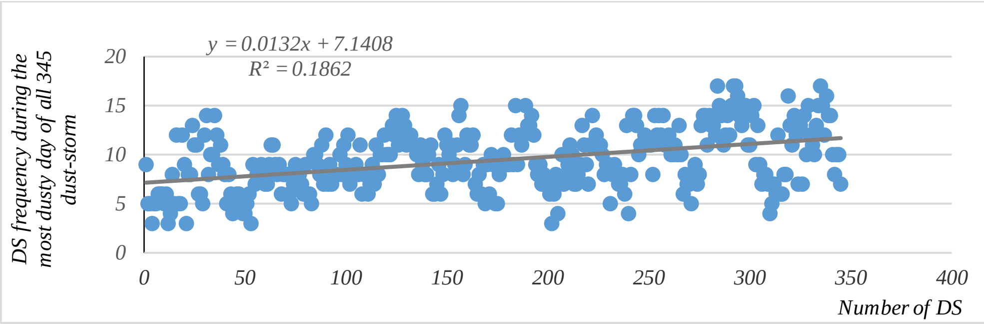

Fig. 5. Scattering of frequency DSs during one decade from 2000 to 2009 over the southern provinces of Iran

Table (3) illustrates the abundance and durability of DSs per year. Winter is the dustiest season in southern Iran, perhaps due to the fact that the maximum southward advance of western winds occur in winter.

Table 3. Abundance and durability of dust storms in southern Iran per year

Abundance and durability	Years	Seasons				Years	Seasons			
		Summer	Spring	Winter	Autumn		Summer	Spring	Winter	Autumn
Abundance of the waves	2000	6	12	10	11	2005	8	8	8	8
Average duration(days)		16.72	7.83	9.38	8.63		12.10	15.75	11.75	12.33
Abundance of the waves	2001	6	6	8	9	2006	7	9	8	8
Average duration(days)		23.33	11.33	13.11	10.99		16.16	9.71	11.22	12.10
Abundance of the waves	2002	7	9	12	7	2007	7	10	11	6
Average duration(days)		14.05	10.22	8.79	12.55		13.05	12.22	8.58	15.83
Abundance of the waves	2003	9	7	9	7	2008	12	10	10	10
Average duration(days)		11.86	13.22	11.13	13.83		8.83	10.07	9.63	8.2
Abundance of the waves	2004	5	7	8	9	2009	11	10	11	9
Average duration(days)		19.83	13.22	12.83	11.22		9.86	9.80	8.59	10.44
		Total of abundance					78	88	95	84
		Decade average (days)					14.58	11.34	10.50	11.62

Since the western winds (westerlies) retreat northward during spring, there were less abundance of dust storms and they did not enter into southern Iran completely during autumn. We distinguished the lowest abundances of dust storms during summer, the season of barotropic atmosphere conditions in the most areas of Iran, particularly in southern provinces.

It seems as though the dust storms during summer are attributed to two warm pressure systems, including summer monsoons and the Sistan Wind (120 days winds).

3.1 Synoptic analysis

3.1.1 Pervasive dust storms

The synoptic patterns were designed for all the groups of dust storms, including pervasive, semi-pervasive, and small ones. Figures (6) represents that the Pakistan Low (Masoudian, 2014) or Indus Low (Barati *et al*, 2014) in every five patterns of pervasive storms was strong and centralized over the west India. Pakistan Low is different from the development of monsoon deep-convection in the Bengal Bay and Eastern India during June and July (Bollasina and Nigam, 2011). The synoptic patterns of all the prevasive dust storms verify the principal route of dusts toward southern Iran from Sahel Band in the south Sahara, southern Hijaz, and ultimately, southern Iran. We could also distinguish other apparant routes from Mesopotamia, central Asia and even Rajistan Desert in India. We could find the route of Sistan Plain in the research by Cao *et al*. (2010). This plain is common between Iran and Afghanistan in western Asia.

The number on the patterns (top-left) presents the common frequency of DSs during all the dust storms in the groups. For instance, number 17 shows that this pattern is composed of 4 weather charts, including the weather charts of Apr 20, 2008; June 17, 2008; July 3, 2008; July 7, 2009. Each chart is related to one storm. During these 4 dust storms, all our selected weather stations (17 DSs) had dust record (06 code). It is obvious that during these all records, Iran, specifically southern Iran, is under low-pressure tonges. We concluded that Pakistan Low became more discharge of air when DSs were more pervasive. In addition, the stronger was Pakistan Low, the stronger the air pumping would be in atmosphere, and consequently, it produced more severe winds (Figs. 6).

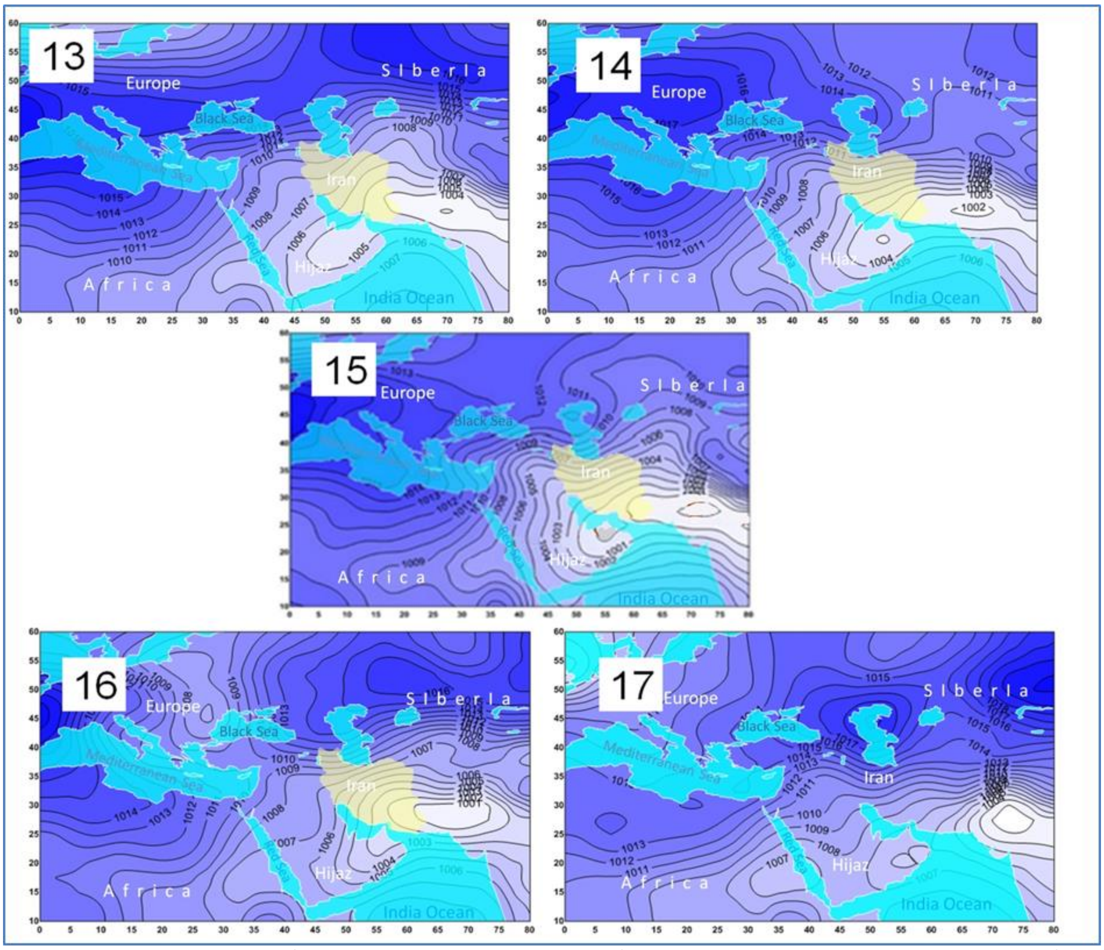

Figure 6. The synoptic patterns of Pakistan Low during the peak days of pervasive dust storms in the southern provinces of Iran (2000-2009). Numbers (top-left) indicate the frequency of DSs during peak days

According to Figure (6), a tongue appeared from the centre of Pakistan Low, which extended over the south Persian Gulf toward Sahel in Africa. This principal tongue is named Southern Iran-Sahel Tongue (SIST).

Sahel area in the south Sahara in Africa is believed to be one of the greatest sources of aeolian soil dust (Goudie and Middleton, 2001) and one of the largest dust producing regions in the world (Engelstaedter *et al*., 2006).

There was adjunct tongue from SIST toward Mesopotamia even to Syria Plain. We called it the Mesopotamia Tongue (MT). Goudie (2014) believed that the above-mentioned alluvial plain was the source of dust in Asia.

The SIST route is extended from the south Pakistan to Hormoz Strait, and then Southern Hijaz, Southern Red Sea, internal areas of Sudan, and finally, Southern Algeria so called Sahel.

Investigating a case study of dust-storm, Ahmadi and Dadashi (2017) concluded that the extreme dust event can be produced with western immigrant system and the polar front jet-stream over Africa, Iraq, Syria, Saudi Arabia and southwest Iran.

Engelbrecht *et al*. (2009) believed that there were the particles of quartz and clay and iron-oxides during dust storms in Arabian countries, including Qatar, Emirates, and Kuwait (Engelbrecht *et al*., 2009). Then the dust deposits were made of the silt materials from Tibesti Massif (Goudie and Middleton, 2001).

3.1.2 Semi-pervasive dust storms

The obtained results demonstrated that all the three Pakistan Low, SIST, and MT patterns appear weaker during semi-pervasive dust storms (Fig. 7). Nevertheles, based on the pattern of 8 DSs to 12 DSs (numbers in top-left), we can see Pakistan Low is more centralized and stronger. The biggest baro-clinic atmosphere in Iran is limited to southeast, which is close to Indus Plain.

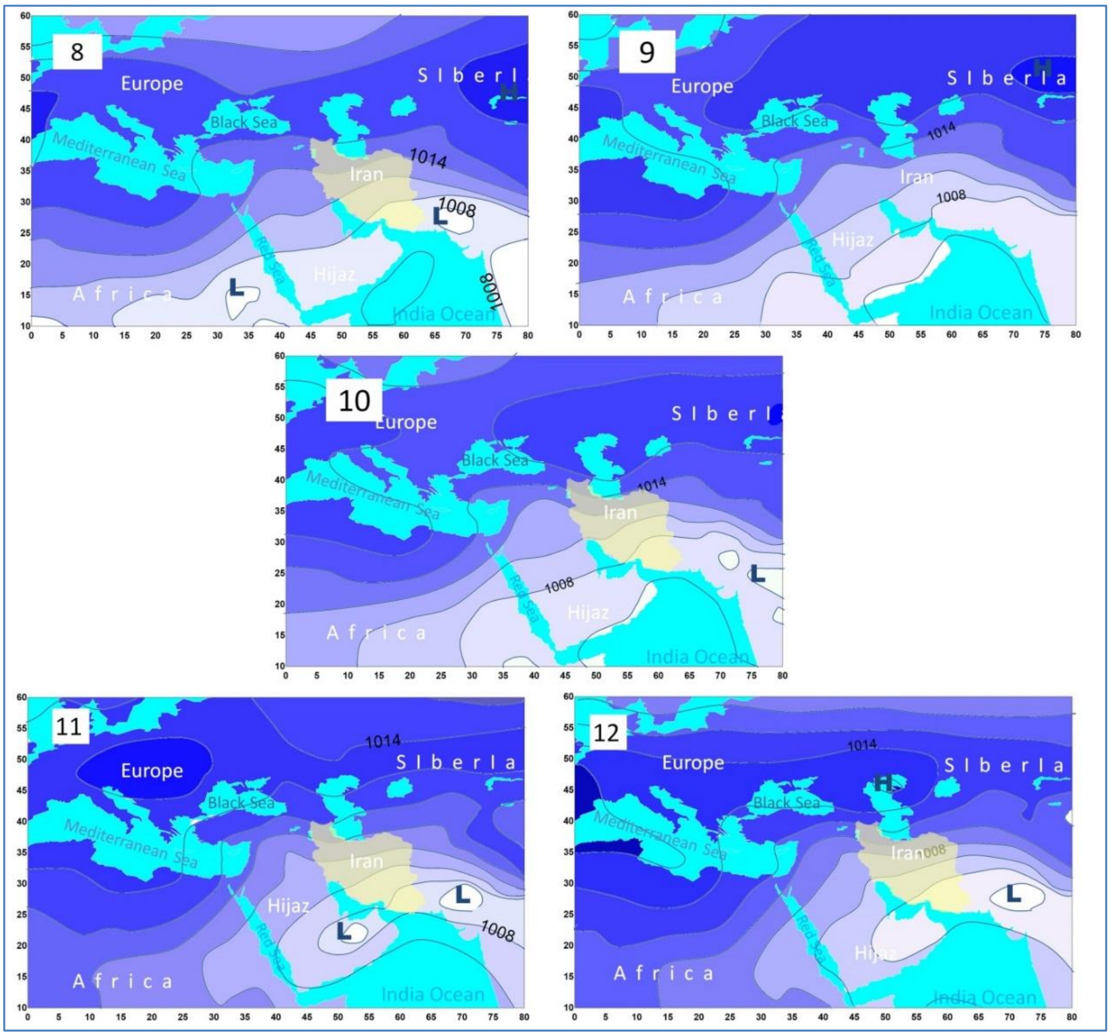

Fig. 7. The synoptic patterns of Pakistan Low location during the peak days of semi-pervasive dust storms over the southern provinces of Iran (2000-2009). Numbers (top-left) indicate the frequency of DSs during peak days

3.1.3 Small dust storms

Small storms were recognized with 3, 4, 5, 6, and 7 DSs during their peak days.
The synoptic patterns revealed apparent differences between small dust storms and pervasive and semi-pervasive ones (Fig. 8):

1) Pakistan Low was absent.
2) SIST and MT disappeared.
3) Iso-bars were formed along the orbital.
Orbital iso-bars could be the signs of weak baro-clinic atmosphere condition and less dust.

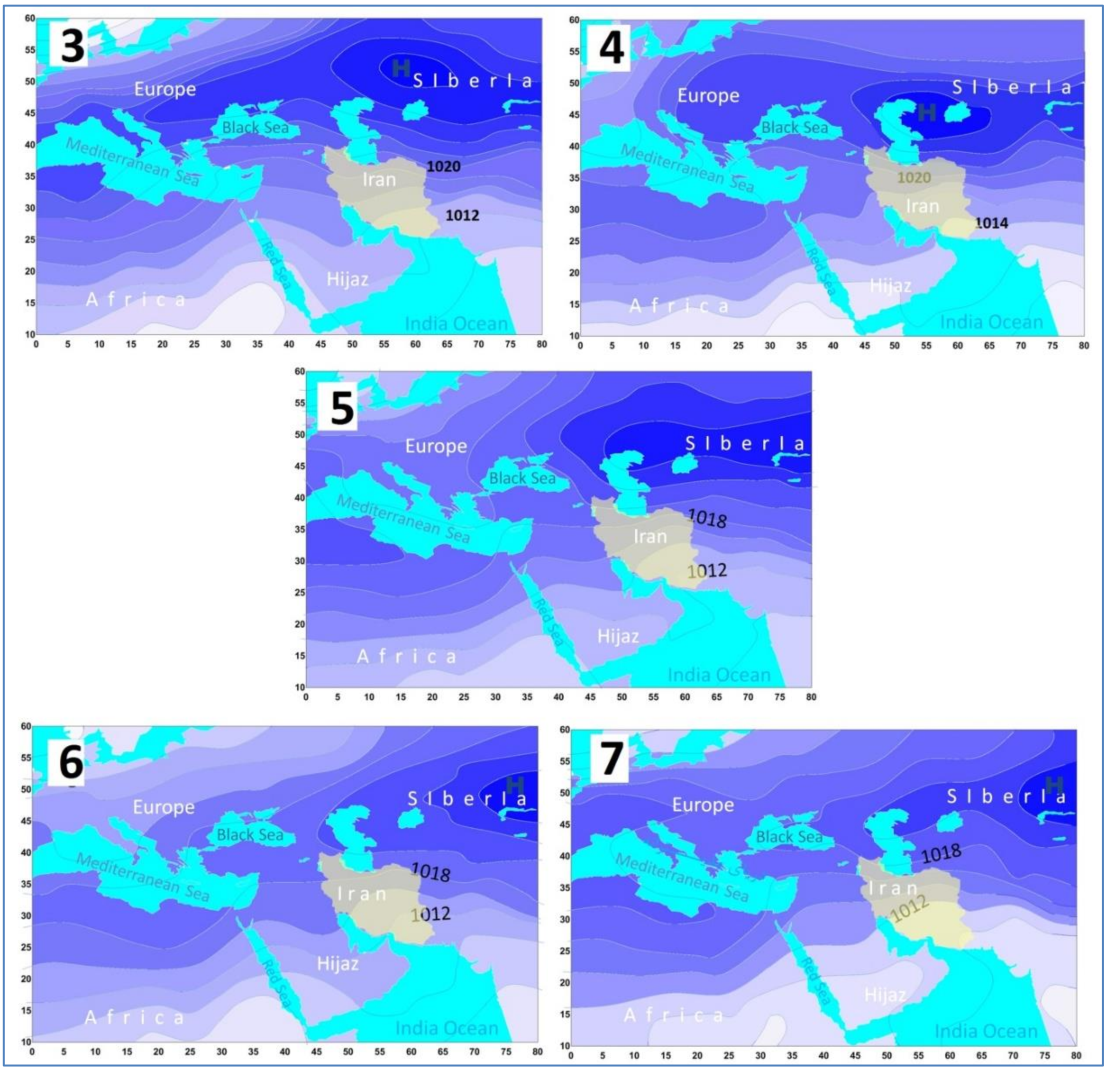

Fig. 8. The synoptic patterns of Pakistan Low location during the peak days of small dust storms over the southern provinces of Iran (2000-2009). Numbers (top-left) indicate the frequency of DSs during peak days

3.1.4 Final patterns

DSs of all the three groups including pervasive, semi-pervasive, and small dust-storms were designed in the final synoptic pattern (Fig. 9). This pattern is related to 345 dust storms. The aggregation of low pressure systems are placed in four locations:
1) The important and major location is related to Pakistan Low.
Figure (9) exhibits that the centre of Pakistan Low has the minimum value of air pressure and it could pump air flows strongly from outside to the inside of the low pressure cell through the main pathways (yellow arrows). The pathways were mostly in warm and dry lands.
2) The second location of low pressure centres could be seen in the south of Persian Gulf and southern Hijaz.
3) The third location of low pressure centres is over the buffer zone between Ethiopia and Sudan.
4) The final location is the low pressure centres of central Sahara. This area is involved in chronic droughts as Sahel droughts.

4. Conclusion

The worldwide and regional maps of soil classification (Barati, 2017; Hadden, 2009) showed that the types of soils in vast territories of the Middle East are covered by aridisols and are very poor soils as entisols. These areas are involved frequently in migrant or in place (non-migrant) low pressure systems. The 28 years of political instability in the Middle East (Shakurnia *et al*., 2013), the lack of knowledge about the environment and its conservation, change of landuse alternatively without rehabilitation, and global warming as a universal phenomenon are four important factors that have intensified the soil degradation and led to erosion, compaction, crusting, and powdering in the southern provinces of Iran.

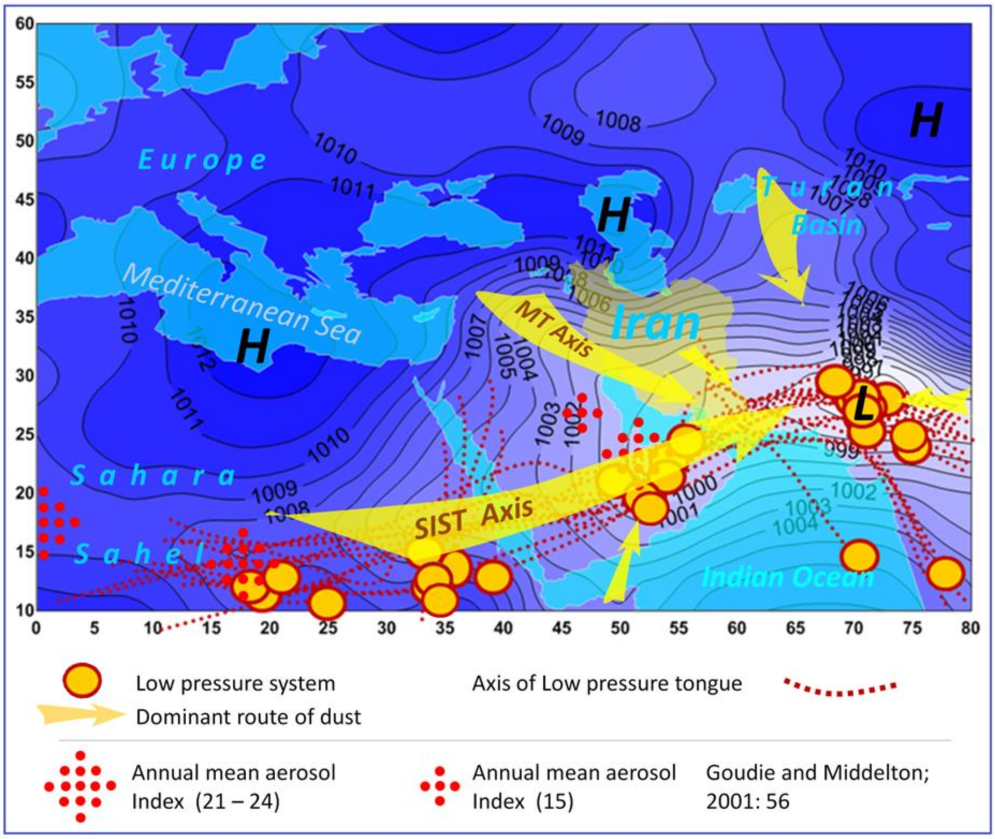

Fig. 9. The synoptic pattern of dust storms over southern provinces of Iran: dust-prone, routs and low pressure systems (2000-2009)

ed The results herein revealed that the pressure system included lows and their tongues could prepare the conditions of dust loading and transferring from dry, warm and far lands, for instance central Asia and Africa (Sahel and Southern Egypt), near lands, such as the deserts of Hijaz and Syria, Mesopotamia Plain, and also internal deserts, Dasht-Kavir and Kavir-lut for instance:

Hijaz: The increase in oil prices increases the farmlands that are located in barren deserts in the form of circle-farms, particularly in Hijaz. The calamity starts once the oil prices decrease. This decrease makes these farmlands change into barren and cosequently, dust-prone areas.

Iraq and Syria: One of the adjunct tongues of Pakistan Low is located on Mesopotamia (MT). Tigris and Euphrates rivers have dispersed silts and clays particles in a big part of Mesopotamia Plain for thousands of years. All the soils in this area are affected by one decade of political instability in Iraq and now Syria, and as a result of the ravages of war in the territory the farmlands were abandoned. The construction of 32 dams on Tigris and Euphrates rivers has decreased their debits by Syria and Iraq (Broomandi, Dabir *et al*., 2017).

Iran: natural and human conditions in Iran increased the abundance and intensity of dust storms in southern areas. Researchers believe the poverty of plant coverage and severe droughts as physical conditions, and over-grazing, dam construction, drying of swamp and estuaries, Hur-al-Azim in particular, and land speculation in urban peripheries as human effects have intensified dust storms in southern Iran.

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