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Original article

Tracing dust sources in different atmosphere levels of tehran using hybrid single-particle lagrangian integrated trajectory (hysplit) model

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A B S T R A C T

The present study aims to tracing dust sources of Tehran (capital city of Iran) using HYSPLIT model and atmospheric circulation systems at different levels. The statistical analyses within the period 1981-2005 indicate that one of the most significant dust events in Tehran province occurred in May 2000 and continued for more than 4 days in Abali, Chitgar, Firuzkuh, Karaj and North Tehran stations. For this purpose, in order to identify the sources of dust particles and their directions, firstly, high-level atmospheric data including zonal and meridional wind, geopotential height at pressure level of 700 and 850 hPa and atmospheric circulation patterns were studied from two days before the storm, the first of May until the end of the second, fourth and fifth day. By using atmospheric circulation maps, the synoptic systems effective in causing dust events, flows directions and their speeds were determined. In this modeling approach, a backward particle tracking method was applied to determine the direction of dust particles, 48 hours before dust storm in Tehran, at three elevations of 100, 500 and 1000 meter. With regard to the fact that the pressure systems of northern latitudes are active over Iran in transition period of spring, it should be noted that the results of the present study were affected by these systems. Results indicate that the high-pressure system hovering above the Saudi Arabia and the low-pressure tongue at higher latitudes play an important role in forming particle motion patterns and flow speeds of mentioned levels. Using HYSPLIT Lagrangian model shows the effects of arid regions of Saudi Arabia, Iraq and some parts of Syria on producing greatest amount of dust particles transferred to Tehran.

1. Introduction

Dust phenomenon which occurs in arid and semiarid lands of the world is closely related to climatic characteristics of the region. According to the World Meteorological Organization (WMO), in a station, whenever wind speed exceeds 15 meter per second and horizontal visibility reduces to less than 1 km, dust storm is reported (Goudie & Mideleton, 2006). Great storms are created when long-term drought occurs and the soil is quite dry (Azimzadeh et al, 2002). Absence of moisture and unstable weather conditions cause dust storms. Intensity and wind speed, aridity and dust particle characteristics are effective in causing such storms (Alijani, 1997). Sometimes, dust particles affected by physical and chemical processes are combined with other pollutants in a long- distance transition and form new compounds (Zhao, 2010). Toxic pollutants which travel with dust clouds can be absorbed into the skin or entered into the respiratory tract and consequently cause skin irritations and respiratory illnesses (Goudie & Mideleton, 2006). Respiratory distresses (Khosraviet al, 2005), increase in energy consumption (Abasi et al, 1999), and photochemical process moderation (Prospero et al, 2002) can be mentioned as other notable examples.

The process of studying and analyzing storm events and tracing dust sources can be performed through different methods. Concerning the frequency of dust storms in the world, Engelstadler (2001) stressed the importance role of dry bed lakes and African great desert as the major producers of dust and considered Sahara to produce dust more than any other desert in the world. After studying the climatology of dust storms in Mongolia, Natsagdorj et al (2002) stated that the highest frequency of dust storm in the west of Mongolia is affected by Gobi Desert and Great Lakes in the west. Wang (2005) studied the formation of dust storms in northeast Asia from synoptical view point and found that dust storms in this region are always accompanied by a cyclone or a low-pressure system and the amount of dust is maximized in the warm sector of the cyclone. Each year, Iran due to its great breadth, diversity of climate and geographical conditions suffers serious casualties and damage from natural disasters. Kutiel & Furman (2003) studies indicated that the highest frequency of dust storm in Middle East is in Iran, Sudan, Iraq and Saudi Arabia. Considering all mentioned above, the aim of studying Iran's capital dust events is to identify particulate emission prone areas by using statistical-synoptic approaches and dust source tracing (HYSPLIT) model (Figure 1).

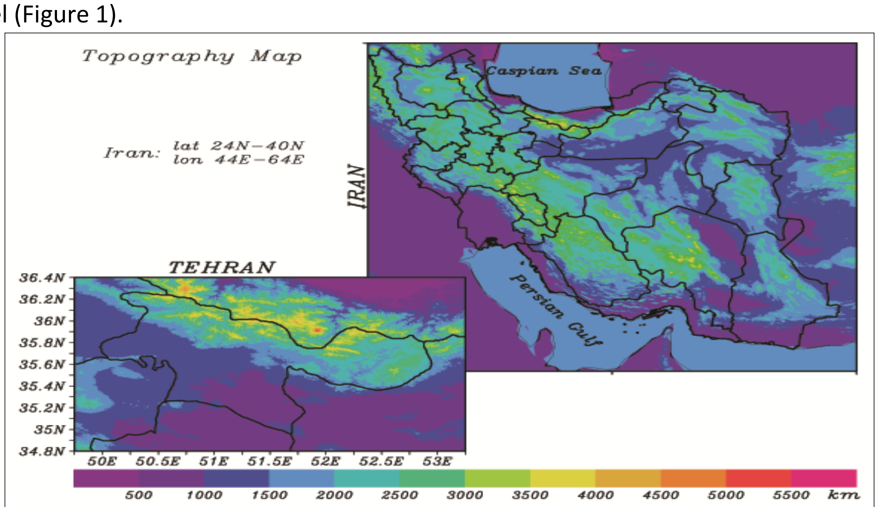


Fig. 1. The topography of the region under study.

Zolphaghari & Abedzadeh (2005) believed that the cause of storms in southeast of Iran is due to exposure to atmospheric flows which bring dust from the arid areas of Iraq. After conducting synoptic analysis of sand storms in Ardakan Plain, Yazd, Omidvar (2006) concluded that dynamic low-pressure systems along with cold front creates vertical flows in a form of severe atmospheric instability that leads to heavy sand storms in the region. Nekoonam (1999) by analyzing dust storms of Sabzevar County proved that no specific discipline exists in causing such an event seasonally over the years, which indicates the changes in factors affecting the cause or aggravation of this phenomenon from year to year. Lashkari et al. (2008) conducted synoptic analysis of dust storms in Khorasan Razavi province within the period 1933-2005. After determining the maximum and minimum numbers of storm events in each station, it was concluded that the high level of pressure and temperature caused strong winds particularly in the southern half of Khorasan Razavi province. By studying vertical distribution of dust dispersion and its sources in the summer 2007 over northeast of Iran using HYSPLIT model, Abdi Vishkaee et al. (2011) concluded that Iran dust sources on August 3-5 were originated from Syria, Iraq and Qom regions (salt lake near Dasht-e Kavir). This event was a response to the strong north winds which blew from Dasht-e Kavir of Qom. However, dust occurred on September 11-13 in Zanjan and Tehran with vertical distribution at low levels of atmosphere originated from Iraq. The results of Mofidi & Jafari (2010) study show that the pattern of the west wave trough extensively provides the dust transition toward southwest regions of Iran. The outputs of HYSPLIT model identify the main sources of these storms within range of center to the north of Iraq and east of Syria to the north of Saudi Arabia. Ashrafi et al. (2011) studied the dust storm directions in several regions of Iran. In their works, HYSPLIT model was used to identify the sources of dust cloud and its type of motion. Based on PM10 dust storm emission algorithm module, the sources provided particles of sand and dust storms on Juan 6-10 over the city of Ahvaz were originated from west of Iraq, boarder of Jordan and Saudi Arabia. In order to assess the ability of RegCM4 model, Mofidi et al. (2012) enclosed the structure of summer dust storms in Sistan Plain. In this study, regional-scale RegCM model was coupled with dust scheme. Model outputs indicated that dust storms are caused due to low-pressure system over Sistan Plain and center of high-pressure system over the east side of Caspian Sea up to the part of the northeast of Iran, which are accompanied by the center of high-pressure system in the range of South Khorasan mountains.

2. HYSPLIT description

The HYSPLIT_4 (HYBRID Single-Particle Lagrangian Integrated Trajectory) model is a complete system for computing trajectories complex dispersion and deposition simulations using either puff or particle approaches. It consists of a modular library structure with main programs for each primary application: trajectories and air concentrations. Gridded meteorological data, on a latitude-longitude grid or one of three conformal (Polar, Lambert, Mercator) map projections, are required at regular time intervals. The input data are interpolated to an internal sub-grid centered to reduce memory requirements and increase computational speed. The modeling system includes a Graphical User Interface (GUI) to set up a trajectory, air concentration, or deposition simulation (Draxler etal, 2009).

In a Lagrangian modeling approach, air concentrations are computed by summing the contribution of each pollutant ‘‘puff’’ that is advected through the grid cell as represented by its trajectory. Under the later approach, modeling the growth of the pollutant puff’s 2nd moments or explicitly modeling the growth of a cluster of particles can simulate dispersion. HYSPLIT can simulate a pollutant distribution starting with a single particle or puff, or by following the dispersive motion of a large number of particles (Escudero, 2006). A common application of atmospheric trajectory and dispersion models is to try to determine the source of a pollution measurement. One common approach is that the trajectory "backwards" from the receptor site can be traced. In the trajectory calculation, this is accomplished by setting the integration time step to a negative value. However, the trajectory only represents the upwind path of a single point, while the pollutant measurement may require of hundreds or thousands of trajectories to represent the dispersion of the pollutant in time and space. Another approach is the run the entire dispersion-trajectory model "backwards" which is computationally attractive because in a 3D particle model the dispersion process is represented by a turbulent component added to the trajectory calculation and the advection process is fully reversible. The stop time of the sampling should be set prior to the start time. All start and stop times should be set to their exact values - relative start-stop times are not supported in the backward mode. To simplify interpretation of the results, horizontal dispersion is "turned off" in the backward calculation, resulting in a more reversible calculation (Draxler, 1999).

3. Meteorological data

Meteorological data for trajectories and dispersion calculations are obtained as output fields from meteorological models. Usually these fields cannot be directly used by HYSPLIT without some pre-processing. Although most meteorological models use some variation of a terrain-following coordinate system, the data fields are usually interpolated to a variety of different vertical coordinate systems prior to output. To maintain a larger degree of flexibility within HYSPLIT's internal structure, i.e. the ability to use different meteorological data sources for input, the profiles of the meteorological data at each horizontal grid point are linearly interpolated to a terrain-following (F) coordinate system,

$\sigma = 1 - z/Ztop$,

Where all the heights are expressed relative to terrain and where Z is the top of HYSPLIT's top coordinate system. The model is capable of handling meteorological data fields provided on four different vertical coordinate systems: pressure-sigma, absolute-pressure, terrain-sigma (typically used mesoscale models covering a limited spatial domain), a hybrid absolute pressure-sigma coordinate system (ECMWF, 1995; which consists of an absolute pressure added to the pressure-sigma level) (Draxler etal, 1998).

4. Data and methodology

In this study, three different phases with statistical, synoptic and modeling approach were adopted respectively.

4.1. First phase

This phase was begun by analyzing data collected from five stations in Tehran within the period 1981-2005. The daily data of dust and visibility less than 2 kilometer were provided from Tehran meteorological organization; furthermore, frequency distribution of monthly, seasonal and annual dust was calculated (Figure 2).

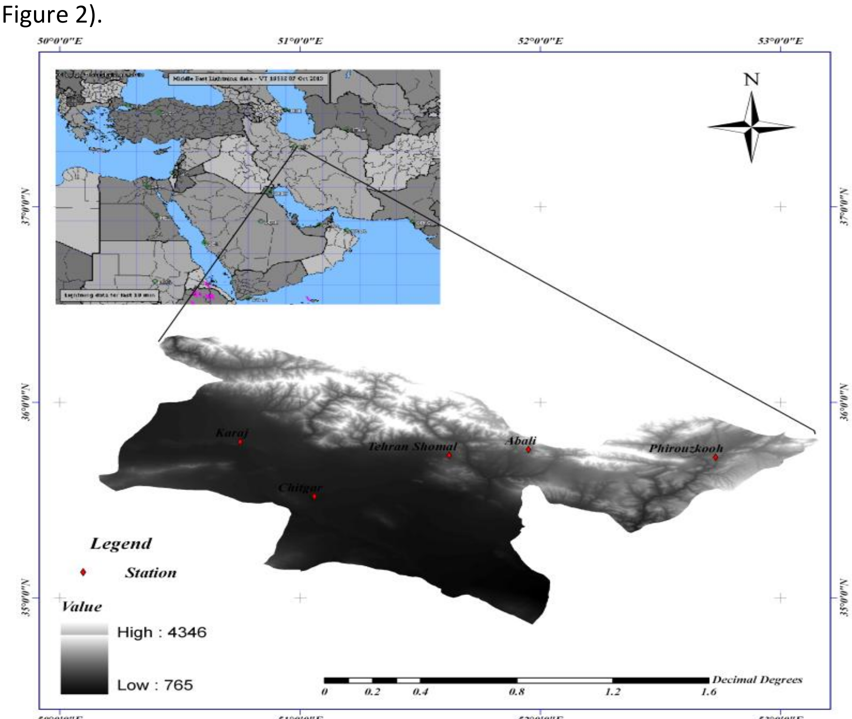


Fig.2. The location of the stations under study.

4.2. Second phase

Causing dust can be considered as response to the vegetation cover change (Engelstadler, 2001), thus the vegetation cover condition and the topology of Tehran were studied using GICC land use data and GTOPO elevation data adopted from the Abdus Salam International Centre for Theoretical Physics (ICTP). Wind speed and atmospheric pressure systems play a major role in causing dust storms (Alijani, 1997); therefore, atmospheric condition at pressure levels of 500, 700 and 850 hPa was analyzed using atmospheric parameters consist of zonal wind, meridional wind and geopotential height with a grid size of 2.5×2.5 degree at three pressure levels provided by National Center for Atmospheric Research (NCAR/NCEP).

4.3. Third phase

In order to identify the dust sources of Tehran, backward movement of dust particles was traced by applying HYSPLIT software within 48 hours before entering to the region for days May 1-5, 2000 at pressure level and three elevation of 100, 500, 1000 meter.

5. Results

Studying the frequency of dust occurred within 24-years in five stations of Tehran indicated that Abali station with the highest elevation of 2465 meter has the most dusty days (109 days) and Chitgar station with the lowest elevation of 1305 meter has the least dusty days (12 days). In addition, Karaj, Tehran and Firuzkuh stations have the highest and lowest frequency of dust respectively (Figure 3). These statistical analyses show that the highest frequency occurred in May 2000 in all stations. As a result, this month was selected as the best time for modeling (Figure 4).

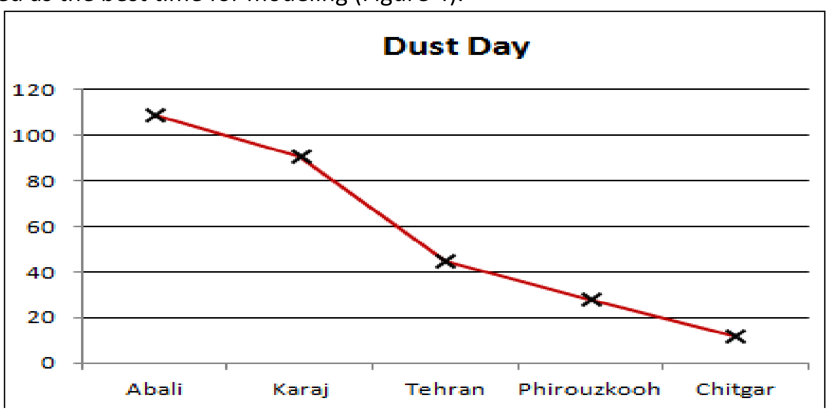


Fig. 3. Dusty days within 24-year period.

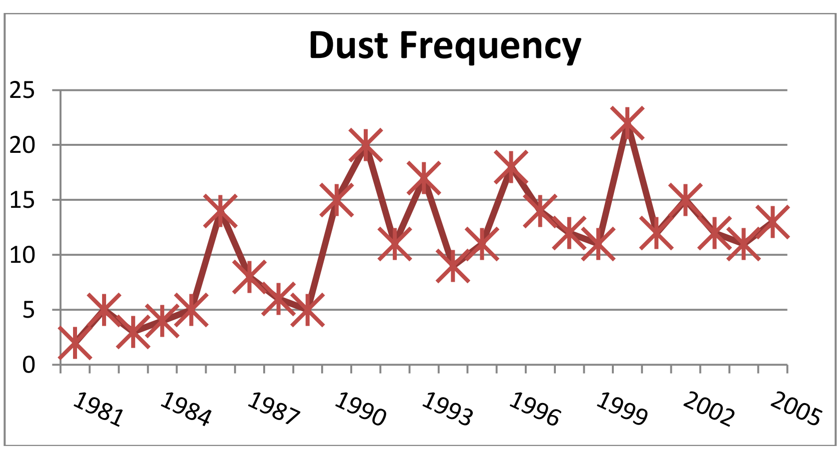


Fig. 4. Annual dust frequency of the stations under study within the base period 1981-2005.

The results of dust seasonal distribution indicate that almost in all stations the lowest amount of dust was observed in summer and fall and the highest amount was observed in spring and winter. Abali station, in winter, has the highest dust frequency (56 percent) and in summer has the lowest dust frequency (2 percent). For Firuzkuh station, the highest (64 percent) and the lowest (6 percent) dust frequency were observed in spring and summer respectively.

Table 1
Seasonal frequency distribution of dusty days (percent).

Station	Winter	Autumn	Summer	Spring
Abali	56	13	2	29
Karaj	11	30	27	32
Tehran	24	9	11	56
Chitgar	79	2	0	19
Phirouzkooh	13	17	6	64

5.1. Land cover

Engelstadler (2001) believes that the density and structure of plants are two major controlling factors in the occurrence and frequency of dust storms. In fact, causing dust can be considered as response to the vegetation cover change. Therefore, the effect of land cover on providing dust sources, increasing or decreasing aerosol concentrations in Tehran district was studied (Figure 4). The studies show that the most part of this district consists of desert and semi-desert lands.

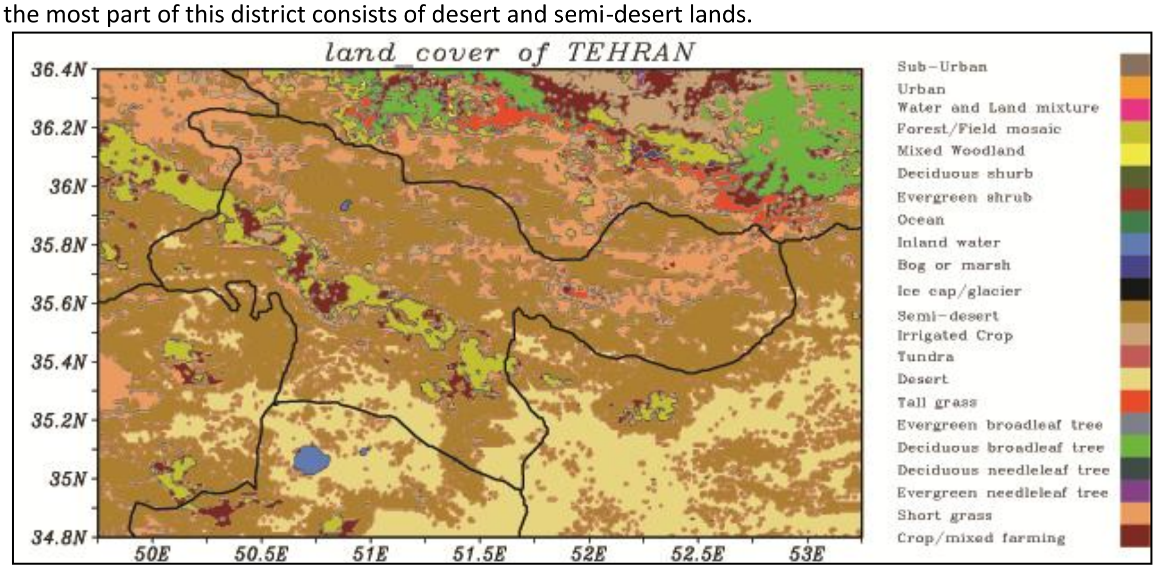


Figure 5. Vegetation cover of the district under study

5.2. Synoptic analysis, identifying sources and tracing trajectory of the dust particles using hysplit model

Concerning the statistical analysis, due to continuity of dust and its high-level concentration in all selected stations in days of May 1-5, 2000; these days were selected for synoptic analyses and identifying sources based on emission algorithm module of HYSPLIT model. In order to perform synoptic analyses, the combined map of geopotential height components and vector components of the wind were drawn at pressure levels of 500, 700, and 850. The pressure levels of 500 and 700 showed similar results in regard to mentioned components. Concerning the fact that the present study was performed in transition period of spring, only the maps at pressure levels of 700 and 850 hPa were considered. In the following, after examining these two elevations, the maps at 700 hPa proved to be more effective in showing the causes of dust in Tehran.

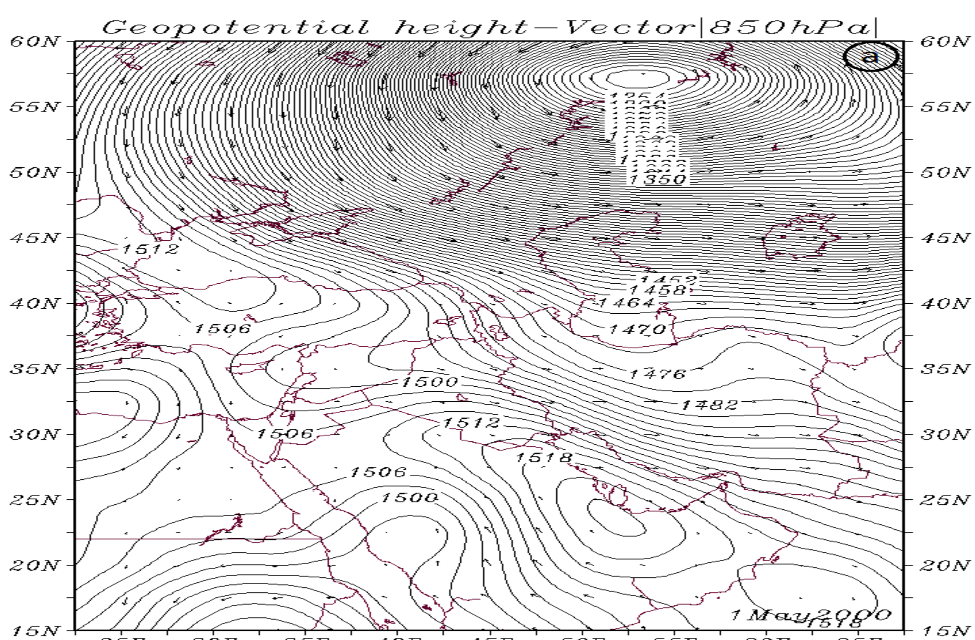
The results of analyzing the components at this pressure level from two days before dust storm on May 1 indicate that formation of two low-pressure systems in northeast of Iran with central pressure of about 2820 geopotential meter at 60°N and a high-pressure system in southeast of Iran with central pressure of 3180 geopotential meter at 22°N have south-oriented and north-oriented directions respectively. These directions at 32°N-40°N latitudes have resulted in compressing pressure lines and increasing wind speeds (Figure 5-b).

On May 1, at the time of dust storm over Iran and Tehran region at 700 hPa, the pressure systems became stronger so that the low-pressure system with central pressure of 2760 geopotential meter with its direction oriented toward south was located at 55°N. The tongues of such a strong center increased the wind speeds at 32°N-40°N by creating a pressure difference with high-pressure system located at low latitudes. Wind vectors indicate the east-oriented direction in the region. In this map, a trough which continued at 38°N latitude and 30°E-35°E longitude causes instability over the mentioned regions, which created dust storm due to lack of moisture and consequently this storm caused pollution and reduction in visibility (Figure 6-b).

Although the map at the level of 850 hPa clearly shows the existence of these two different pressure systems, which increase pressure difference over the region, the component of wind at the level of 700 hPa has higher rate of speed in compression with level of 850 hPa (Figure 6-a).

Concerning the performed synoptic analyses and HYSPLIT model outputs, the main mechanism of dust particles was about dust particles transition in the area limited to east and south east of Mediterranean, Saudi Arabia and Iraq toward the region under study. In the pressure pattern hovered over the region at the time of dust, the directions of particles transition at the three levels of 100,500 and 1000 meter is depended to the west wind direction and speed (Figure 6-b). The other important point obtained from studying model outputs on may 1 and 24 Hours before it, until the earlier hours of may 1 is that particle transition occurred horizontally and at the elevation over 1000 meter. Particle transition which was east-oriented has a vertical leap in earlier hours of May 1, in a way that it drew to the elevation over 2000 meter in some cases. However, flows direction by the end of the day has not steady progress and in the middle and later hours of the day, dust particle movements toward lower layers was drawn to about 100 meter (Figure 6-c).

One of the reasons for fluctuating feature of dust particle transition from origin to the region under study is that since this event occurred in transition period of spring in which pressure systems of north latitudes are still active over Middle East, it disrupts the function of high-pressure system of lower latitudes. In this case, it caused instability and dust storm.



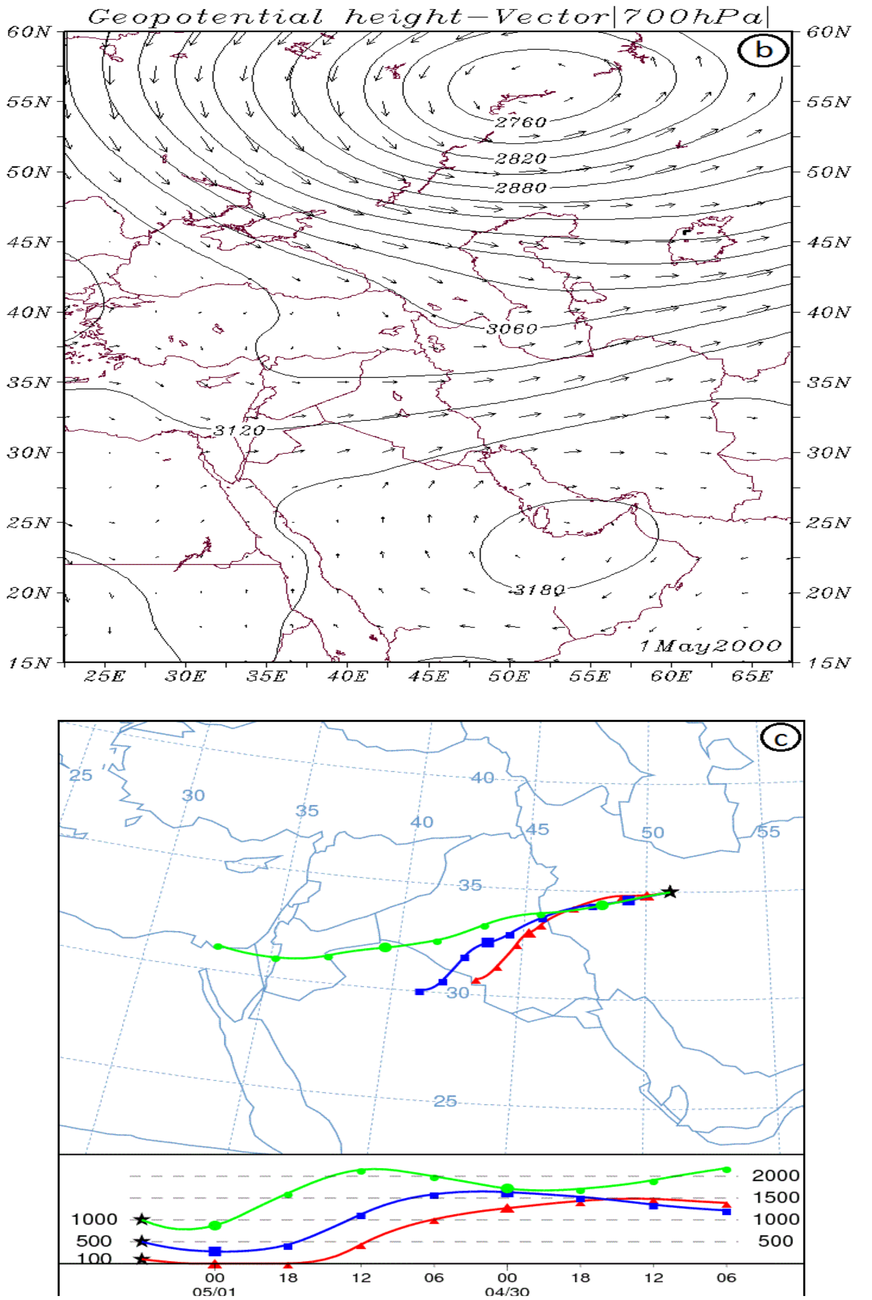


Fig. 6. Average daily of geopotential height and vector wind on May 1, 2000 at two pressure levels of 700 and 850 hPa (alb) and dust particle tracing map(c).

On May 2, dust flows direction over Tehran was in lower latitudes (32°N-35°N) due to deepening the trough (Figure 7-b). East-oriented movements of this trough with the elevation of 3120 geopotential meter in Syria caused dust transition toward Tehran. The model indicates that in Syria, in this day, dust particles at the elevation over 1500 meter followed horizontal direction and had negligible amount of vertical dispersion. However, while moving to the east, these particles transited toward Tehran at elevation of 500 meter with a vertical leap in the later hours of the day (Figure 7-c).

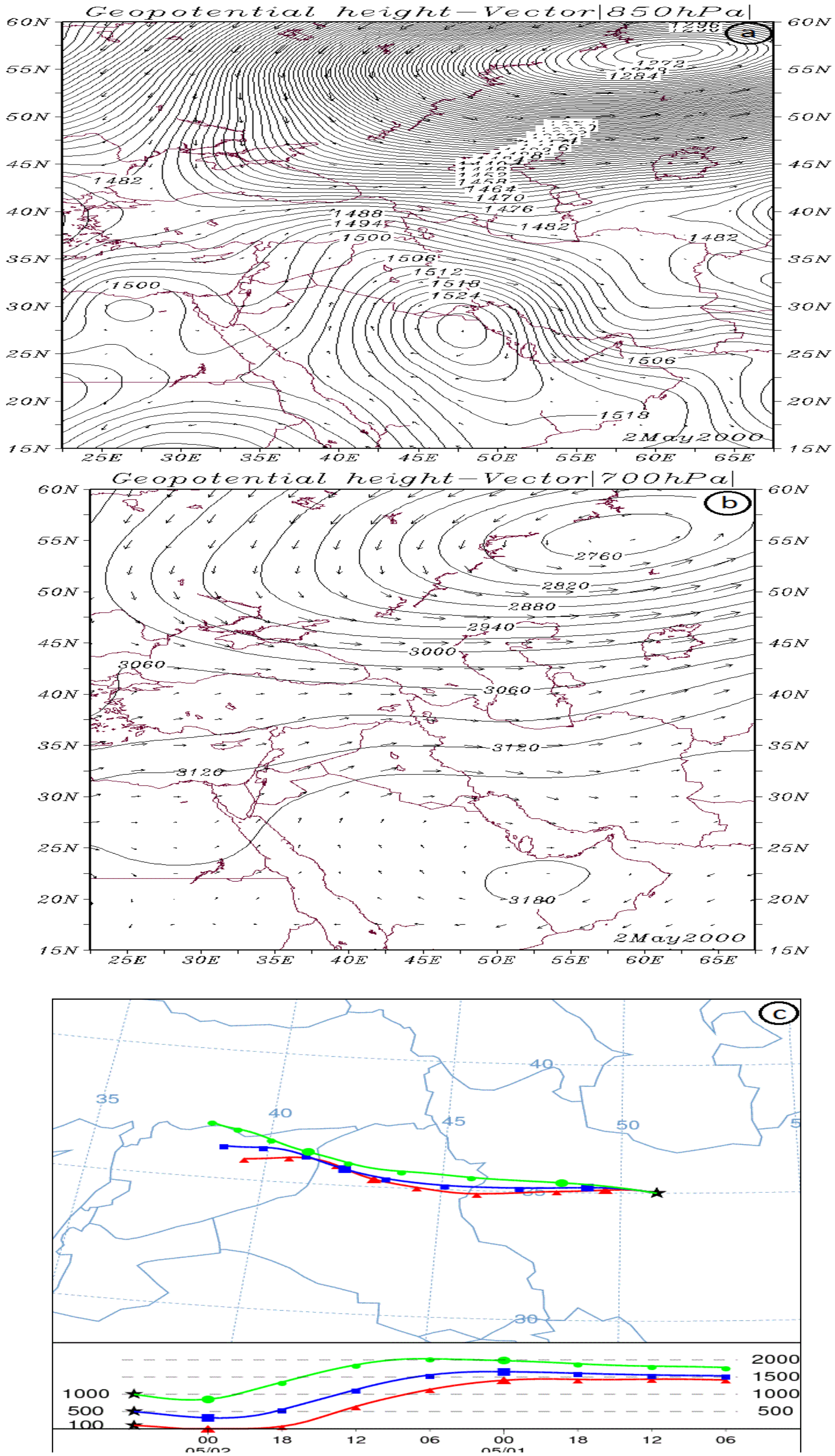


Fig.7. Average daily of geopotential height and vector wind on May 2, 2000 at two pressure levels of 700 and 850 hPa (a,b) and dust particle tracing map (c).

On May 4, low-pressure system had north-oriented flows and its center was located far away from Iran. Accordingly, the effects of this low-pressure system transited to the north latitudes so that in this day high-pressure system covered nearly all parts of Iran. However, by advancing a weak low-pressure system in the north of Mediterranean, its tongues were caused to make a pressure gradient affected by high-pressure flows at lower attitudes. This pressure difference increases wind speeds and forms flows from southwest to the northeast. These flows had east-oriented direction over Iran (Figure 8-b). Affected by these flows, tracing map observations indicate that Tehran's dust storm was originated from Saudi Arabia. In origin, the dust particles of May 4 began their transition toward the east at lower levels compared to other days and in destination descended at elevation lower than 100 meter (Figure 8-c). The main reason for particles to descend over Iran is the high-pressure system domination which is stranger than other systems (Figure 8-b).

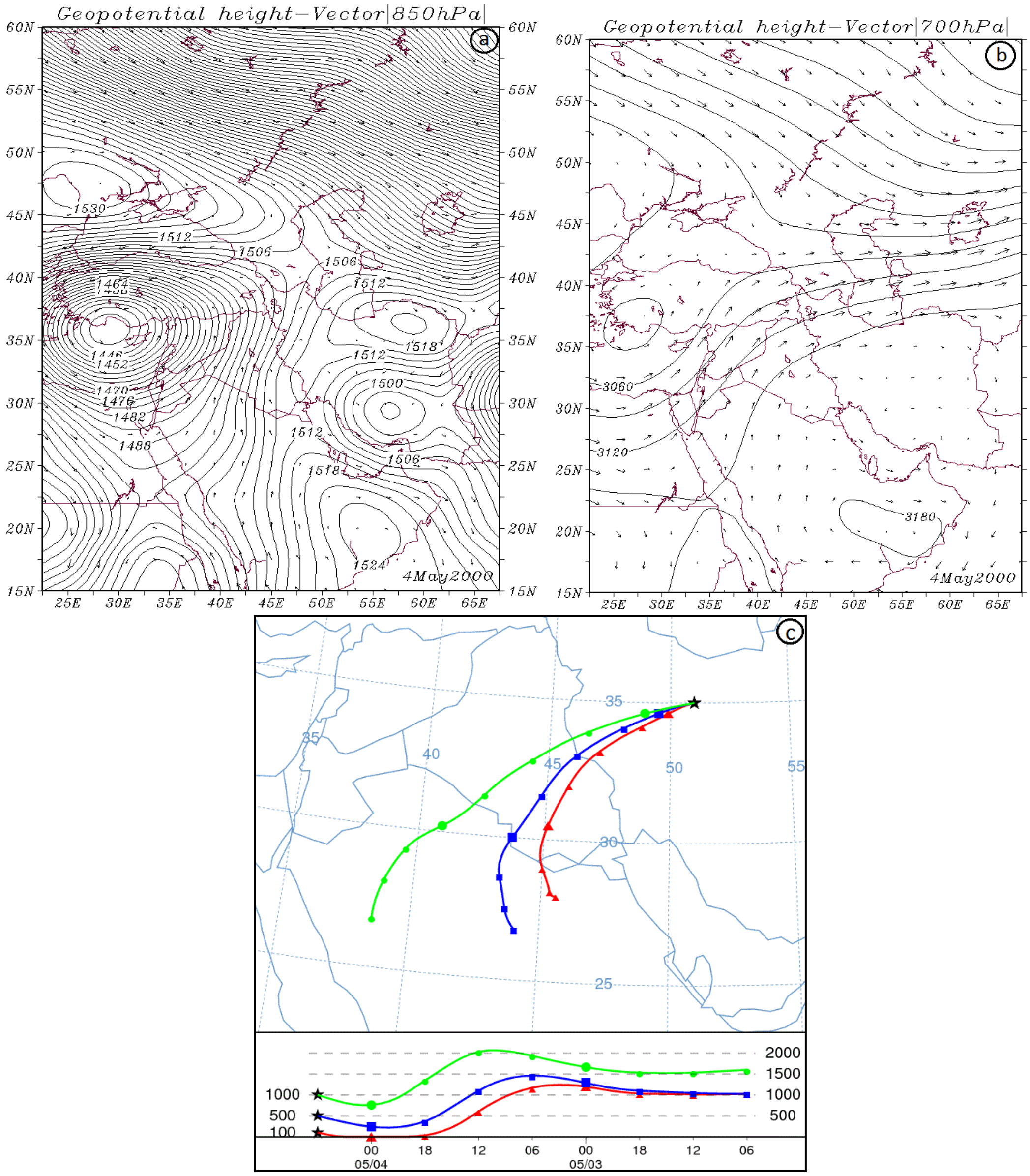


Fig. 8. Average daily of geopotential height and vector wind on May 5, 2000 at two pressure levels of 700 and 850 hPa (a,b) and dust particle tracing map (c).

By studying dust dispersion direction in the last day of the dust storm (May 5) over the region, a different pattern can be found compared to other days. In this day, in the one hand, particles originated from Iran were observed; on the other hand, these particles fell into circular movements over Iran. The center of high-pressure system hovering over Saudi Arabia and low-pressure system in north of Mediterranean at the level of 700 hPa was still active in this day and caused pressure difference and increased wind speeds with southwest-northeast direction. This state was similar to the state of earlier days. However, forming the center of high-pressure system in the northeast regions of Iran created a new circular pattern that helped to find the origin of dust particles over the region. Dust particle transition affected by anti-cyclonic flows hovering above Saudi Arabia and cyclonic flows stalled over Mediterranean had east-oriented direction toward Iran. Here, due to existence of anti-cyclonic flows (clockwise) resulted from high-pressure system formed in northeast of Iran, particles changed their direction and fell into circular movements (Figure 9-b). Model output of May 5 indicates that the aerosols originated from Iran transited at the lowest elevations compared to those originated from Iraq (over 1500 meter and in Iran was lower than 1000 meter) (Figure 9-c). The transition of aerosols which originated from Iran can be related to the desert and semi-desert cover lands of the region (Figure 5).

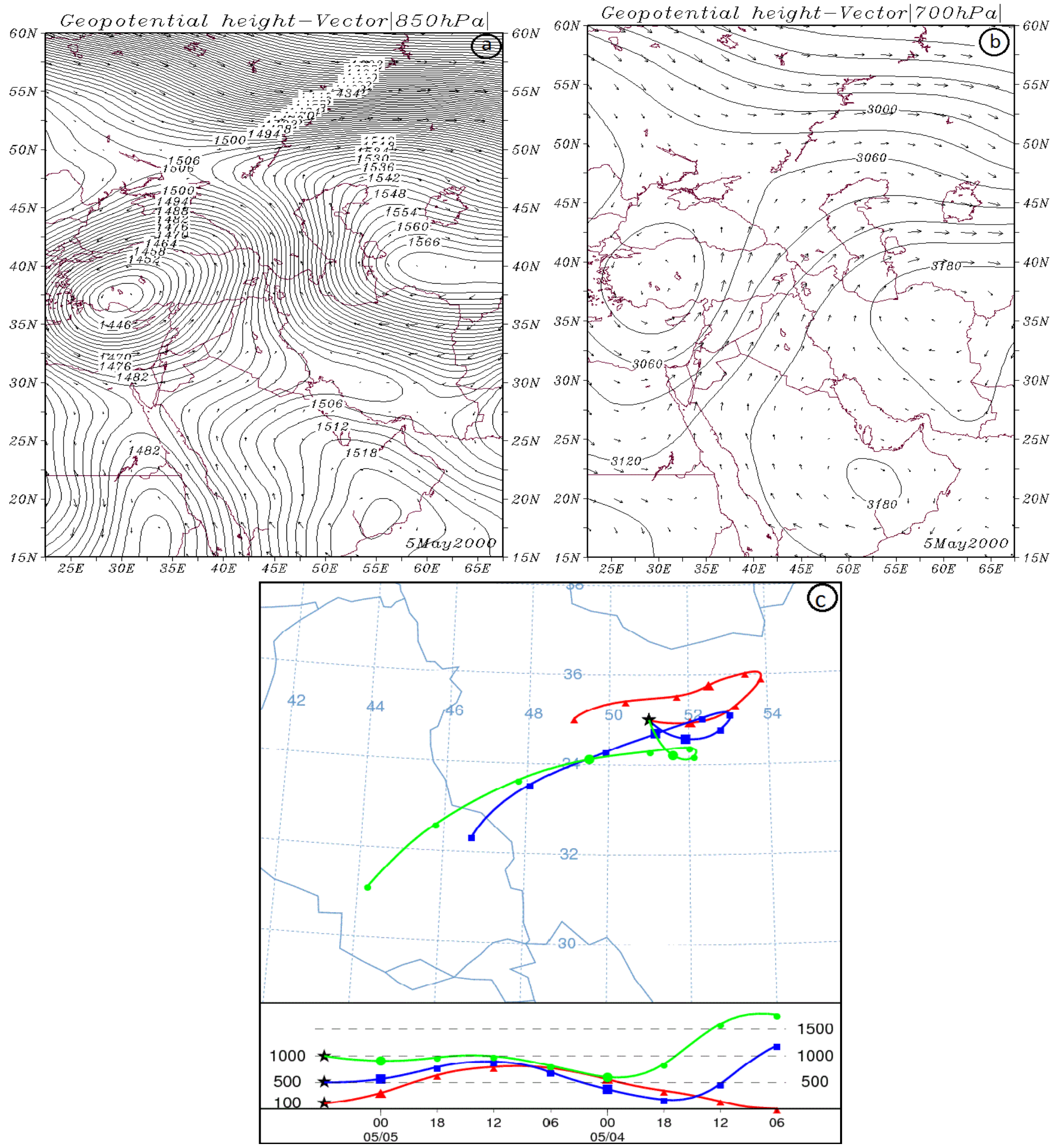


Fig. 9. Average daily of geopotential height and vector wind on May 5, 2000 at two pressure levels of 700 and 850 hPa (a,b) and dust particle tracing map (c).

6. Conclusion

The results indicate that within the period 1981-2005, the higher frequency of dust was in May, spring of 2000. In spring, the highest frequency of dust was observed in all stations under study. The 24-year dust frequency of five synoptic stations shows that Abali Station had the highest number of events (109 days) and Chitgar station had the lowest number of events (12 day).

Since in transition period of spring pressure systems of north latitudes are still active over Iran, the present study which was conducted in May was affected by these systems. The observations at the level of 700 hPa indicate that one of the pressure systems causing dust and determining its direction is the pressure system has hovered above Saudi Arabia which had little displacement during all dusty days and thus it was considered as a permanent system in the region. Other effective pressure system in Tehran dust storms was the low-pressure system in the north of Iran. This system affected the region along with high-pressure system over Saudi Arabia in first and second of May. However, in fourth and fifth of May, due to the movement of the mentioned system toward the north, cut-off low-pressure system was formed over the north of Mediterranean, which partly affects pressure lines, speed and direction of flows.

Studying particles transition directions of HYSPLIT model outputs indicates that the main Tehran's dust sources are located generally at 25°N-37°N latitudes within range of Iraq, Saudi Arabia and Syria. Surveying the elevation data of the emission particles shows that dust particles in higher layers flowed toward Iran and reached Tehran at lower levels. In studying the pressure systems, firstly, dust particles transmitted to the higher levels by low-pressure system and drawn to the high-pressure over Saudi Arabia, then descended to the ground level. In general, anti-cyclonic flows dominate this area.

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