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The Effect of Dust Aerosols on Some Meteorological Parameters in Two Dry and Humid Areas

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Abstract
The current study compares the effect of dust aerosols on two meteorological variables, temperature and relative humidity, in two different regions. For this purpose, AOD data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used for Kermanshah and Ahvaz from 2010 to 2015. In a subjective review, a day with the highest AOD value was highlighted. The effects of dust on temperature and relative humidity variations were investigated on the selected day and compared with a clean day. The effect of aerosols on the vertical profile of temperature shows that increasing aerosol concentrations in Kermanshah causes a rise in temperature at lower atmosphere during the day due to the absorption of solar radiation by dust aerosols and a decrease in temperature at night due to the longwave radiative cooling. Because of the high seasonal humidity in Ahvaz, the nature of the aerosols has resulted in the greenhouse effect, which has raised the temperature by absorbing radiation at night. The effect of aerosols on the vertical profile of relative humidity differs between Kermanshah and Ahvaz. The relative humidity has risen, particularly at lower levels in Ahvaz during the dusty days and nights. The increase in aerosols in both Ahvaz and Kermanshah regions had no effect on precipitation based on data from the Iran Meteorological Organization. The reason could be lack of precipitating systems in the two regions during the warm seasons.

Keywords: Aerosol, MODIS, Dust, Temperature, Relative humidity.

1. Introduction
Aerosols are natural or anthropogenic suspended solid or liquid particles in the atmosphere. These particles influence Earth's climate both directly, by scattering and absorbing sunlight, and indirectly, by altering the reflectivity of clouds (Tegan and Lacis, 1996; Haywood et al., 2005; Nabat et al., 2015; Ramachandran, 2018). Almost 40% of aerosols in the lowest layer of the earth's atmosphere (troposphere) are dust. The Sahara Desert, the Arabian Peninsula, Iraq, Iran, Central Asia, northern China, and Mongolia contribute 90% of the dust (Shao et al., 2011). Dust can be mixed by atmospheric turbulence within the planetary boundary layer and transported long distances by wind (Zhang et al., 1997; Schepanski et al., 2009).
Dust aerosols have a direct, semi-direct, and indirect impact on global and regional energy budgets, as well as cloud and precipitation formation (Weaver et al., 2002; Miller et al., 2004; Mallet et al., 2009; Huang et al., 2014). The radiative impact of aerosols and their interactions with clouds are affected by dust particle size distribution (Mahowald et al., 2014). Shortwave radiation size order particles typically produce radiative cooling per unit mass, whereas longwave radiation size order particles typically produce radiative warming per unit mass (Miller et al., 2006). According to the IPCC Fifth Assessment Report (AR5), dust's annual average direct radiative effect is approximately − 0.10 W m^{-2} on the global scale (Intergovernmental Panel on Climate Change (IPCC), 2013). It varies from − 0.30 to + 0.10 W m^{-2} among different global climate models (Stocker et al., 2013). However, it is not clear that dust aerosols have a net warming or cooling effect on the global climate (Tegen et al., 1996; Miller et al., 2006; Xie et al., 2018). In general, the

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radiative effects of dust aerosols can be either warming or cooling depending on absorption or reflection, but the net effect is warming (Kok et al., 2017).

Furthermore, these particles have a semi-direct influence on the formation and lifetime of clouds due to the absorption of radiation, which changes the air temperature, humidity, and vertical stability of the air column (Hansen et al., 1997; Ackerman et al., 2000; Miller et al., 2004; Su et al., 2008; Tegen & Heinold, 2018). Several previous studies examined the effect of direct and semi-direct aerosols on regional climate and found that dust could increase or even suppress rainfall (Nabat et al., 2015; Gu et al., 2016; Wu & Yi, 2017).

Asia is one of the substantial deserts and anthropogenic dust-laden regions in the world (Hsu et al., 2004). Annually, particularly in the summer and spring months, dust storms related to Shamal and Levar winds are active in the Middle East and the Arabian Peninsula (Rezazadeh et al., 2013; Shalaby et al., 2015; Awad & Mashat, 2016). Also, anthropogenic dust emissions contribute to the total aerosol loading in these areas and have increased due to the rapid increase in population and energy consumption (Burney & Ramanathan, 2014). Dust storms occur on a regular basis in countries with arid and semi-arid climates, such as Iran, and have both external and internal causes (Boloorani et al., 2014). A study on the effects of dust on temperature, humidity, cloudiness, and precipitation in Iran (Ilam province) during the cold seasons from 2000 to 2013 found that on dusty days, temperature decreased, relative humidity and cloudiness increased, and precipitation was suppressed at all stations (Zarif Moazzam et al., 2018).

In this study, we look at dust effects in two geographically distinct regions of Iran (Kermanshah and Ahvaz cities) with completely different moisture and temperature climate. We examine the effects of dust on some meteorological variables such as temperature and relative humidity over these two regions of interest using data from six years (2010-2015, only May to October). The following is how the paper is structured. Section 2 describes the data and methodology; Section 3 examines the effect of these particles on the temperature and humidity of different layers of the atmosphere in these regions with varying amounts of moisture on specific days based on the increasing aerosol optical depth (AOD). The conclusion is presented in Section 4.

2. Data and Methodology

2-1. Aerosol data

The AOD is used to characterize aerosol data. It is a dimensionless parameter that depicts the concentrations of aerosols in the vertical column of the atmosphere over a specific location. It denotes aerosol loading values and is a measure of the amount of solar beam extinction caused by dust and other aerosols in the atmosphere. The AOD characterizes aerosol data. It is a dimensionless parameter that shows aerosol concentrations in the vertical column of the atmosphere over a specific location. It represents aerosol loading values and is a quantity of the solar beam extinction due to dust and other aerosols in the atmosphere (Bruce, 1995). The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is aboard the Terra and Aqua satellites. Terra passes from north to south across the equator in the morning, while Aqua passes south to north over the afternoon. Terra MODIS and Aqua MODIS view the entire Earth's surface every 1 to 2 days (Kaufman et al., 1997). This study uses AOD data from the Aqua satellite's MODIS instrument. The Aqua MODIS monitors the Earth's surface and atmosphere in 36 wavelength bands (0.412 to 41.2 m) with spatial resolutions of 250 m, 500 m, and 1 km. MODIS atmospheric products are available at various processing levels that describe their spatial and temporal resolutions. In this study, the MODIS Aqua level-3 atm daily global product (MYD08 D3) is used. It contains daily 1 degree grid average atmospheric parameter values.

2-2. Temperature and relative humidity data

The ERA-Interim 2-meter air temperature and relative humidity (00UTC, 06UTC, 12UTC, and 18UTC) data were provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). The spatial resolution is 0.75° × 0.75°, and the time step is 6 hours.

2-3. Regions of interest

The present study analyzes two critical climatic zones of Iran with high frequency of dust storm events, Kermanshah and Ahvaz. Kermanshah is the contre of Kermanshah Province and is located in western part of Iran (34.3277°N and 47.0778°E), while Ahvaz, the contre of Khuzestan, is located at 31.318327°N and 48.670619°E. Figure 1 depicts the locations of these cities, created using Earth Topography (ETOPO2) data from the National Geophysical Data Center in the United States (http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html). The two selected regions (Kermanshah and Ahvaz) have high dust concentrations in dust storm events compared to other areas in western, southwestern, and southern Iran (Rajaee et al., 2020). As illustrated in Figure 1, these cities are approximately 365 km apart and have vastly different topographic conditions. Kermanshah is situated in a mountainous region. Ahvaz, on the other hand, is relatively flat and close to the Persian Gulf. Another notable distinction between Kermanshah and Ahvaz is their climatology.

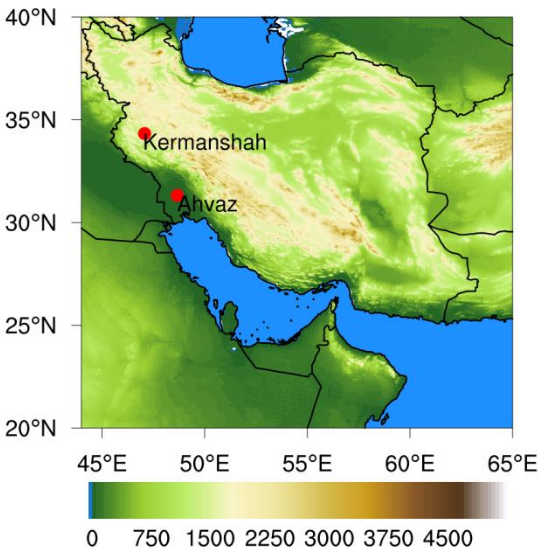


Figure 1. Iran's topographic map (elevations in meters). The red circles indicate the locations of Kermanshah and Ahvaz cities.

2-4. Methods

In this study, AOD data were extracted from MODIS Aqua level-3 atm daily global product (MYD08_D3) for six years between 2010 and 2015 in Kermanshah and Ahvaz regions. Then, the effect of aerosols on the vertical profiles of temperature and relative humidity was investigated on a selected dusty day (July 22, 2010). This dusty day is chosen from one month of a year with the most increase of aerosol concentration according to AOD values.

3. Results and Discussion

Figure 2 depicts the monthly mean AOD values for July (2010 to 2015) in Kermanshah and Ahvaz. These areas of Iran experience extreme dust events, especially in spring and summer, because of their proximity to vast deserts (Hamidi et al., 2013; Yousefi et al., 2020) and are located on the prevailing large-scale atmospheric currents, mainly from North Africa. As can be seen from this figure, the general variation of the annual AOD in the two cities is similar, with the highest values for Ahvaz city. This difference in the AOD values of these two cities is related to the Kermanshah's height and distances to some sources of dust storm feeder area. The Kermanshah region is generally cold and dry in the winter and warm and dry in the summer. As a result, the atmosphere is more light transmission in both summer and winter. The stability of the atmosphere in Kermanshah during the winter makes it a city with a clear sky, but in summer, the small scale eddies develop in the area and also intrusion of dust from far sources of dust, mostly from the North African area (Khalidy et al., 2019). The situation in Ahvaz is a little bit different. Because of its proximity to a watery southern span, this city experiences hot and humid summers and relatively mild and less humid winters. Being close to the sea also provides it with some local weather systems, which may affect the contaminant of the air over the city.

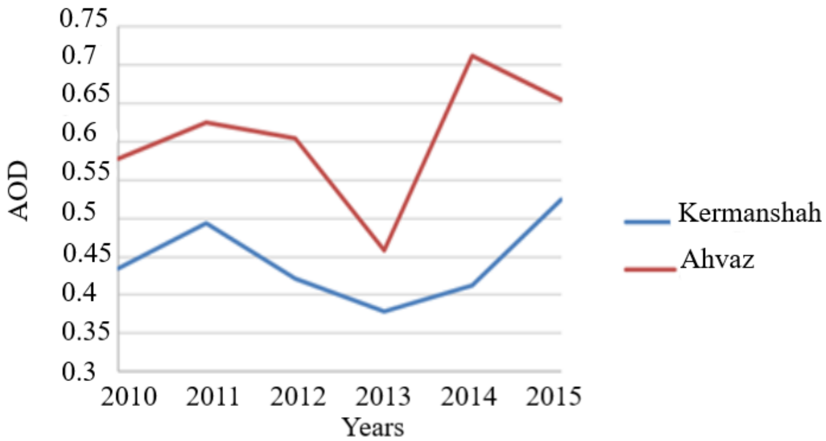


Figure 2. Variation in the monthly mean AOD values for July (2010 to 2015) of Kermanshah (blue) and Ahvaz (red).

Figure 3 depicts the variation of AOD values in Kermanshah and Ahvaz regions during July 2010. The day of July 22, 2010, which had the highest AOD value in both regions, has been focused on. Both cities experienced a peak in AOD values on July 22, 2010. This peak is clearly visible in their records when compared to the values of other days. In addition, contrary to previous assessments of the two cities' climatology, Ahvaz had polluted days throughout July (AOD greater than 0.5), whereas Kermanshah was cleaner than expected (AOD is less than 0.5 or close to 0.5). In July, just three days were polluted in Kermanshah, but this number is 23 days for Ahvaz. Considering Figure 4 and the AODs of the entire region of West Asia and North Africa, the contamination of the atmosphere of the Ahvaz is not advective dust, but it should be from local dust convection. Some of it might be due to agricultural activity in the area, which is very high in July.

Figure 4 depicts that AOD values were mostly higher over Ahvaz during the dust storm event on July 22, 2010. The dust storm covered the southwestern parts of Iran, including Ahvaz. Considering the chronology of the dust storm on 22 July and the air flows in the area (Figure 5), one can conclude that, in addition to the local triggering of the dust storm, advection of dust from the south, primarily from North Africa, particularly at higher levels of the atmosphere (Khalidy et al., 2019), enhances the dust storm over western Iran. Advection from the outside and convection from the inside are combined to form a heavy dust storm with high AOD values (2.59 in Ahvaz) (Figure 4c).

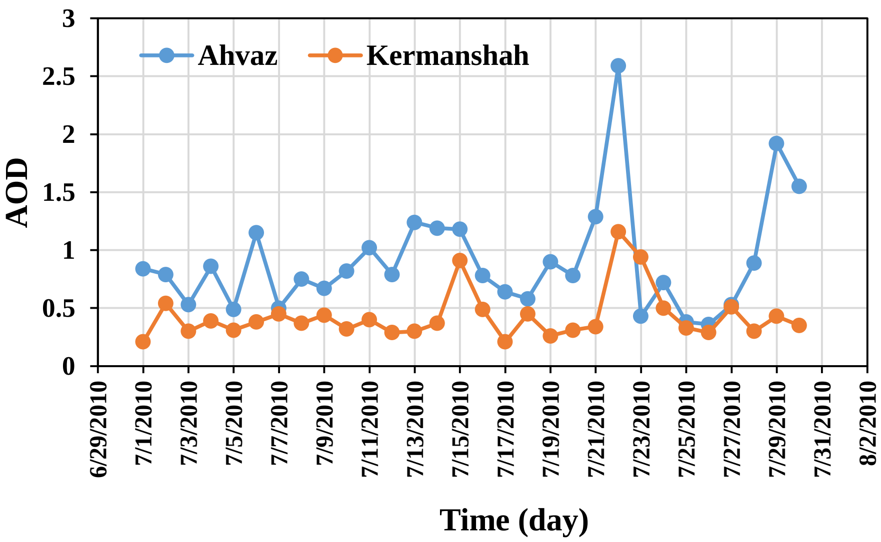


Figure 3. AOD variation on a daily basis in Kermanshah and Ahvaz in July 2010.

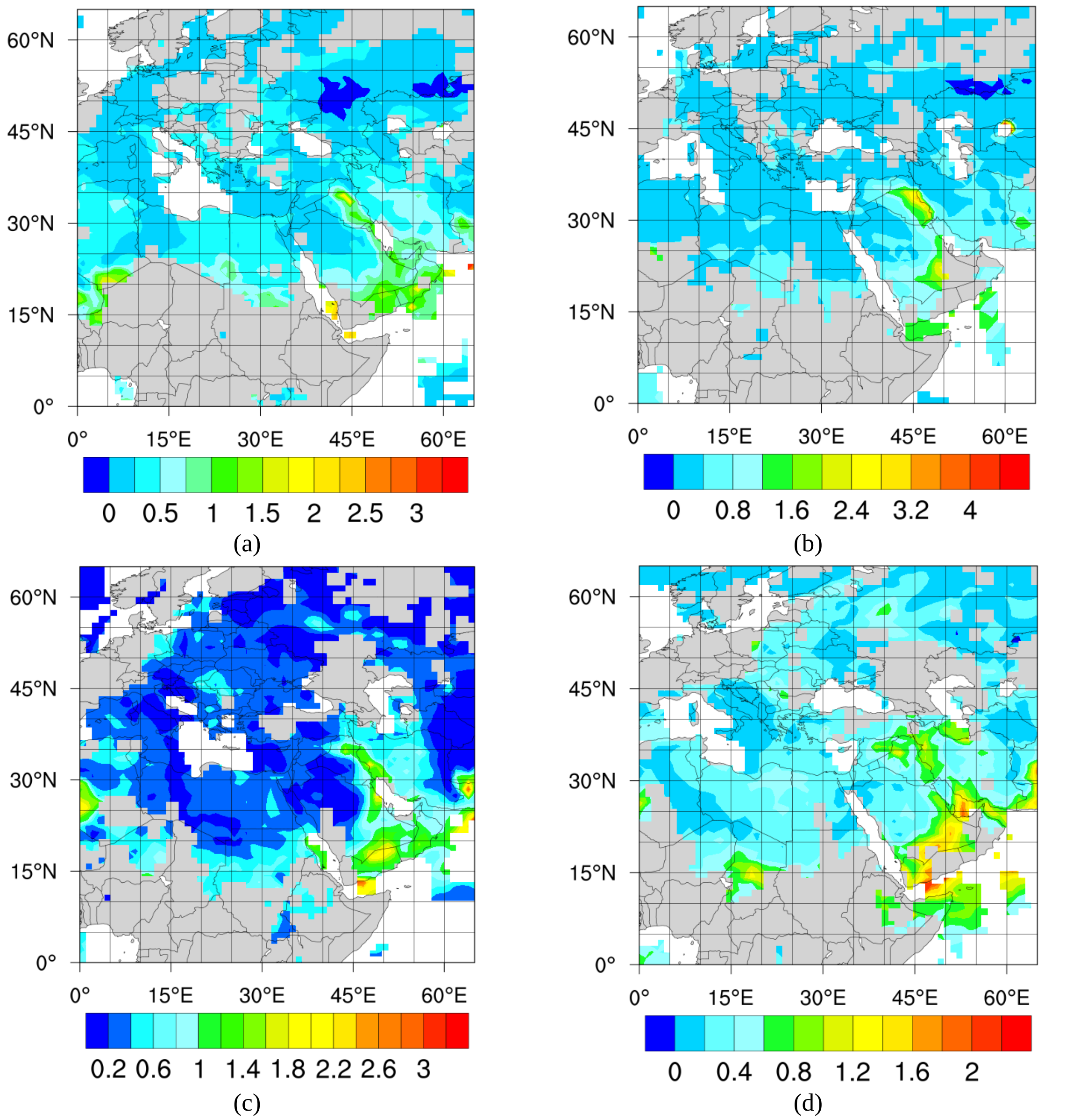
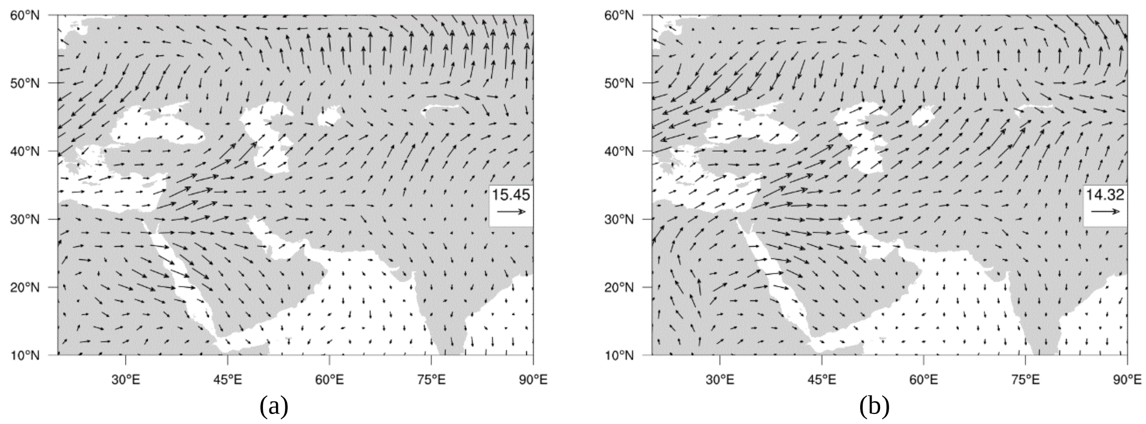
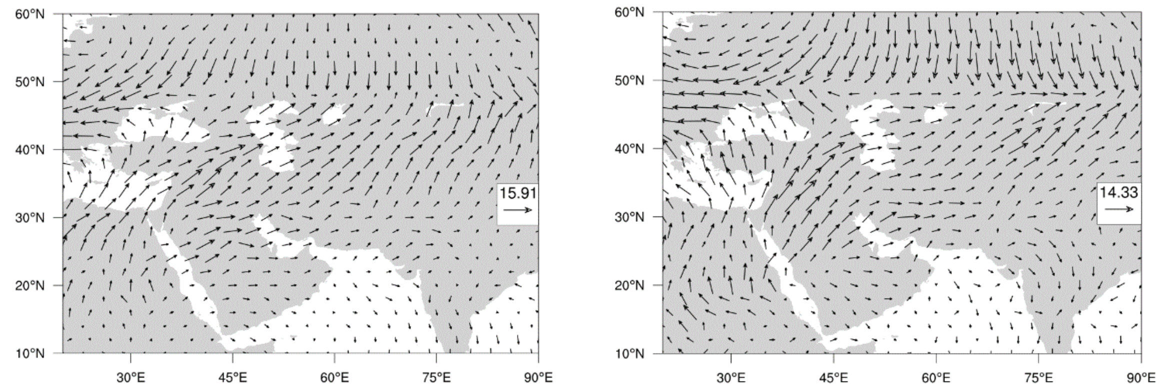


Figure 4. The spatial distribution of AOD of the region a) 20, b) 21, c) 22, d) 23 July 2010. The black circles indicate the locations of Kermanshah and Ahvaz cities.





(c) (d)

Figure 5. The patterns of 1000 hPa wind (m s^{-1}) on July 22, 2010 at a) 00:00 UTC, b) 06:00 UTC, c) 12:00 UTC, and d) 18:00 UTC. This visualization makes use of Global Forecast System (GFS) data with a horizontal resolution of 0.5 degrees (https://www.ncei.noaa.gov/data/global-forecast-system/access/grid-004-0.5-degree/analysis/).

After demonstration dust in the area of consideration, its effect on atmospheric variables, particularly temperature and relative humidity values, was quantified by plotting the vertical temperature profile on a clear day (July 20, 2010) and a dusty day (July 22, 2010). This selection was based on AOD values in these two days based on the results of Figure 4.

The vertical variation of temperature in Kermanshah has been plotted in Figure 6 for four different times (00, 06, 12, and 18 UTC) of the 22 July as a polluted day and the 20 July as a clear day (without dust). Comparing the vertical profile of the temperature in dusty and clean days of Kermanshah city shows that the temperature at lower levels of atmosphere and surface is less than clear times (Figures 6a and 6b). It might be due to nighttime and early morning long wave outflow radiation or nocturnal surface cooling. However, dust aerosols are not a barrier to longwave radiation, but since they could play as nuclei for the condensation process, the concentration of water droplets might happen and increase near the surface where the available water contents are higher (Figure 8a). As the day progresses, the humidity begins to fall (Figure 8b). The opposing processes affecting air temperature compete until warming by intercepted radiation advances, warming becomes greater than nocturnal cooling when humidity almost disappears (Figures 8c and 8d)—as time passes, this difference narrows as the temperature of the air rises due to the sunlight inflow. In this case, dust acts as a barrier to sunlight, and warming the surface is reduced on a dusty day compared to a clean day. This process continues until the end of the day, when warming the surface has the greatest value, resulting in the most significant difference between a dusty and a clean day. Although Figure 6 depicts the surface pressure level as 1000 hPa, it is worth noting that because the Kermanshah altitude is approximately 1200 m higher than the free sea surface, the profile from 850 hPa should be considered. The source of this inconsistency is data provided by the ERA-Interim model. Depending on the vertical expansion of dust aerosols, the old regime of the temperature variation at the surface (2 m) achieves deep in the atmosphere up to 600 hPa level. By decreasing the dust concentration with height, the influencing processes inverse until the dust contaminant disappears and the difference vanishes (Figures 6c and 6d). The effect of aerosols on higher-level temperature values becomes negligible. Because of the two processes of absorption and dispersion, aerosol particles reduce intercepted solar radiation. As a result, the effect of aerosols in high levels of the atmosphere is negligible (Figure 6).

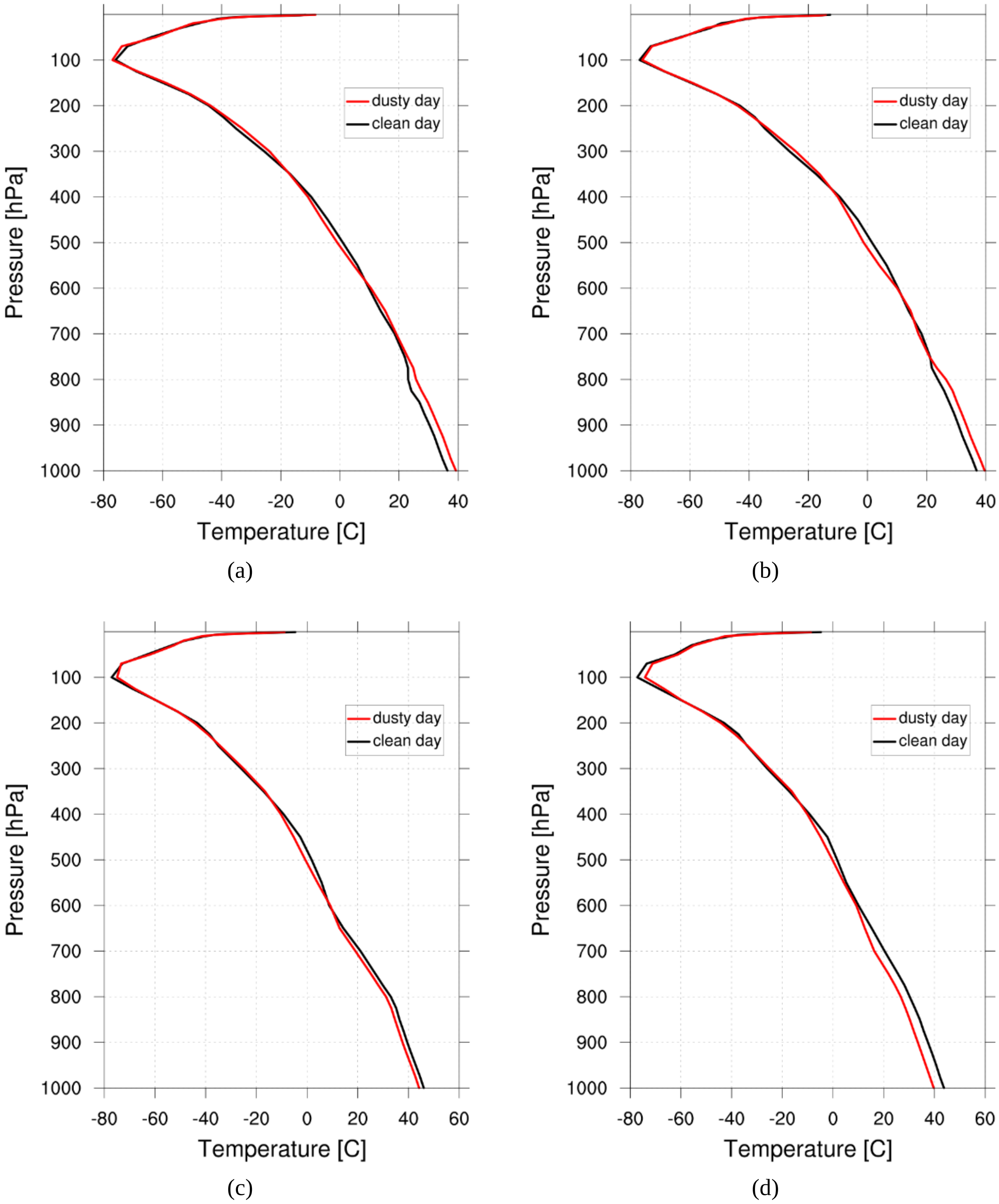


Figure 6. The vertical profile of temperature (^{o}C) a) 00, b) 06, c) 12, d) 18 UTC (-3.5 local time) on July 20, 2010 (clean day) and July 22, 2010 (dusty day) in Kermanshah city.

Figure 7 depicts the vertical temperature profile of Ahvaz on clean and dusty days (20 and 22 July 2010, respectively) in six-hour intervals. This graph shows that, despite Kermanshah, an increase in aerosol concentration has no effect on temperature at lower levels. Nonetheless, the warming of layers between 700 and 500 mb (mid-levels) is greater in Ahvaz than in Kermanshah.

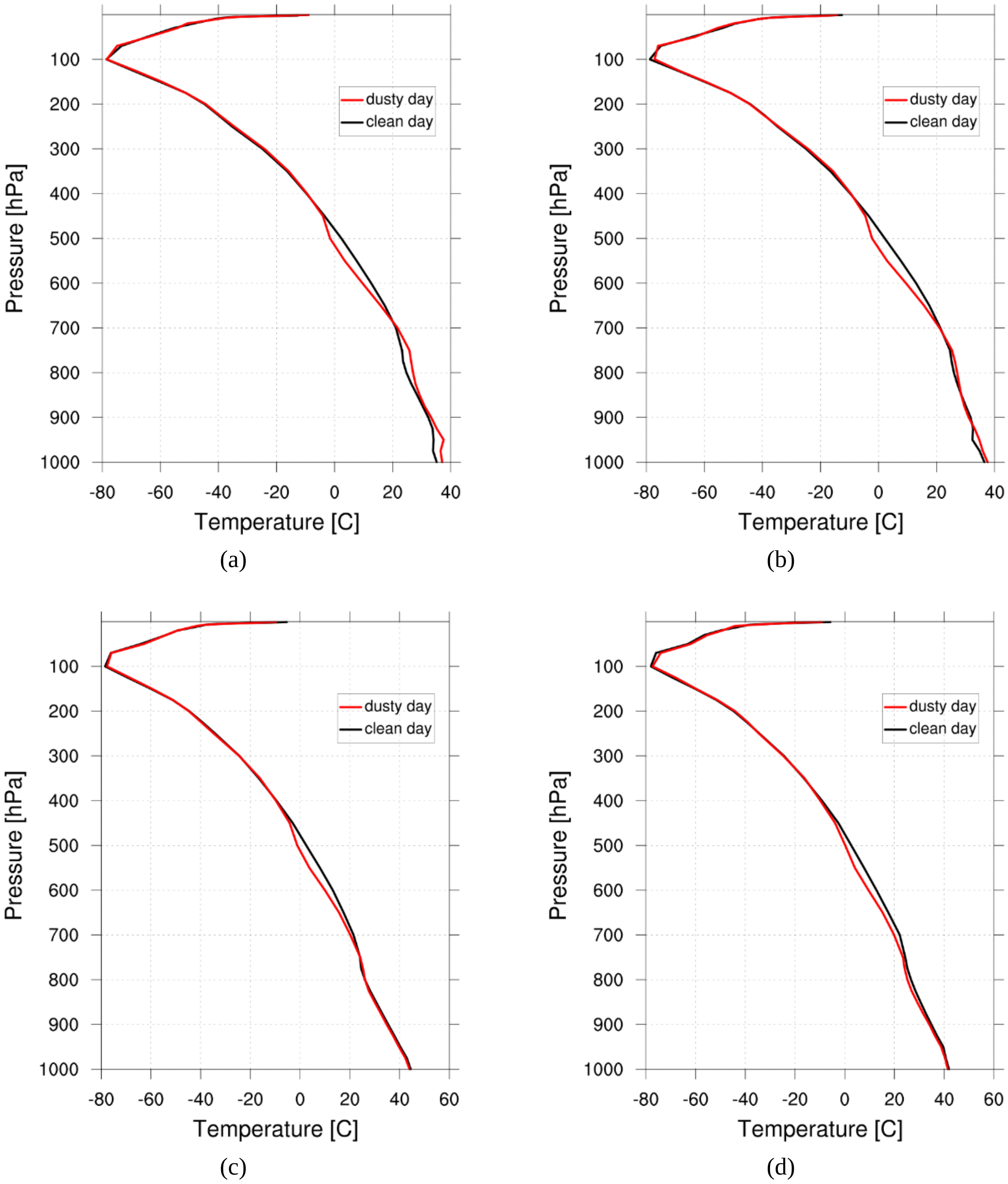


Figure 7. The vertical profile of temperature (^{o}C) a) 00, b) 06, c) 12, d) 18 UTC (-3.5 local time) on July 20, 2010 (clean day) and July 22, 2010 (dusty day) in Ahvaz city.

Figures 8 and 9 show the vertical profile of relative humidity on clean (July 20, 2010) and dusty (July 22, 2010) days at six-hour intervals (00, 06, 12 and 18UTC) in Kermanshah and Ahvaz, respectively. Figure 8d shows that the relative humidity at 700 hPa increases at night local time. No precipitation was reported on this day based on data from the Iran Meteorological Organization, mainly attributed to the high concentration of aerosols caused by the dust storm.

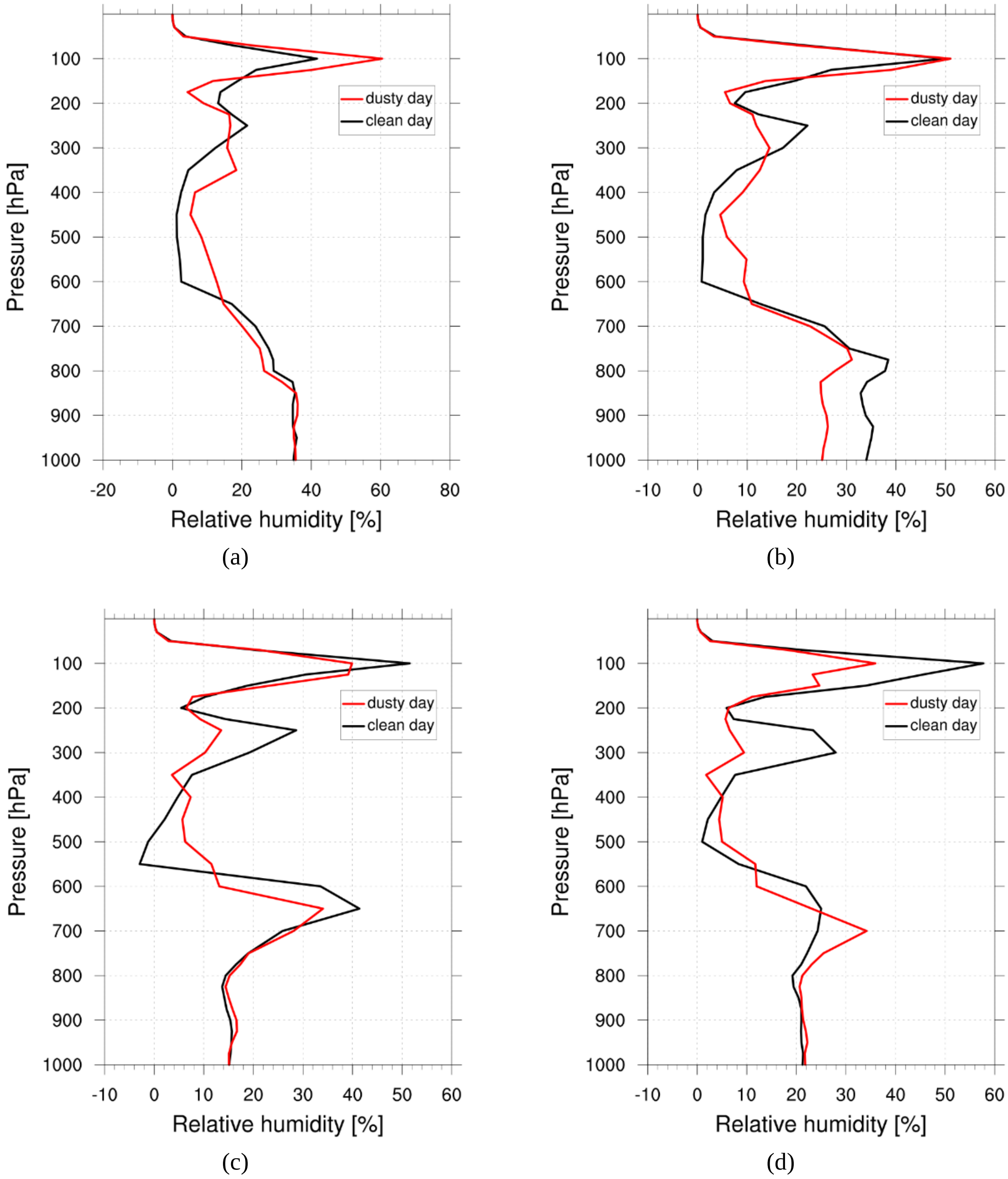


Figure 8. The vertical profile of relative humidity a) 00, b) 06, c) 12, d) 18 UTC on July 20, 2010 (clean day) and July 22, 2010 (dusty day) in Kermanshah city.

The effect of aerosols on the vertical profile of relative humidity in the two regions of Kermanshah and Ahvaz is not identical, and it increased relative humidity, particularly at lower levels in this area during the day and night of dusty days.

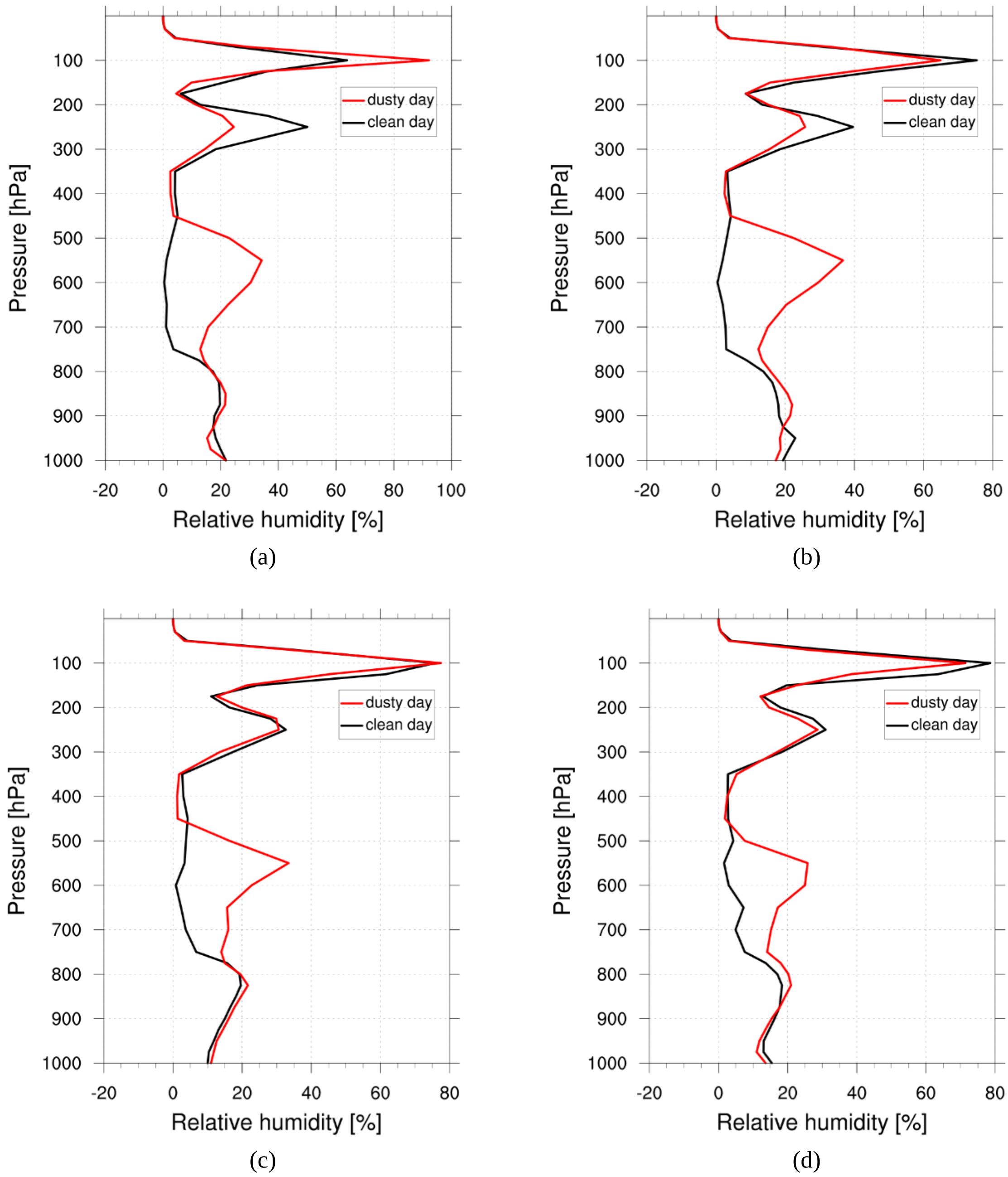


Figure 9. The vertical profile of relative humidity a) 00, b) 06, c) 12, d) 18 UTC on July 20, 2010 (clean day) and July 22, 2010 (dusty day) in Ahvaz city.

4. Conclusion and discussion

During the warm seasons of 2010 to 2015, the effect of dust aerosols on temperature and relative humidity in two dry (Kermanshah) and wet (Ahvaz) areas was studied. First, using AOD data from the MODIS satellite, the days with high AOD values were chosen for further investigation. The effect of increasing dust concentration on daily vertical profiles of temperature and relative humidity was then investigated. According to satellite images, dust particles are the primary aerosols in these areas. A comparison of annual AOD values from 2010 to 2015 revealed that Ahvaz city had the highest AOD values. The difference in AOD between these regions is due to differences in topography and proximity to dust sources.

The effect of dust aerosols on the vertical temperature profile varies between Kermanshah and Ahvaz. Increased aerosol concentrations in Kermanshah cause a rise in temperature at the lower atmosphere during the day due to the absorption of solar radiation by dust aerosols and a decrease in temperature at night due to longwave radiative cooling. This finding is consistent with previous research (Nabat et al., 2015; Najafi et al., 2017). Furthermore, increases in solar radiation absorption and scattering by aerosols, as well as the greenhouse effect of moisture, have resulted in the most negligible impact of dust aerosols during the day (Kautzman, 2014). The effect of aerosols on the vertical profile of relative humidity differs between Kermanshah and Ahvaz. The relative humidity has risen, particularly at lower levels in Ahvaz during dusty days and nights.

The increase in aerosols in both Ahvaz and Kermanshah regions had no effect on precipitation. Higher atmospheric aerosol concentrations contribute to the formation of more cloud condensation nuclei, reducing mean cloud droplet size by reducing coalescence and droplet collision efficiency. This both reduces and delays rainfall (Nabat et al., 2015; Gu et al., 2016; Wu & Yi, 2017; Zarif Moazzam et al., 2018). Another reason could be a lack of precipitating system in the two regions during the warm seasons.

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