British Journal of Applied Science & Technology
18(6): 1-10, 2016; Article no.BJAST.31460
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Impact of Dust Storm Intensity on Some Metrological Elements and Aerosol Optical Properties (Case Study: Baghdad, Iraq)

Saadiyah H. Halos[1*], Monim H. Al-Jiboori[2] and Osama T. Al-Taai[2]

[1]Atmosphere and Space Science Center, Directorate of Space Technology and Communication, Ministry of Science and Technology, Baghdad, Iraq.
[2]Department of Atmospheric Science, College of Science, Al-Mustansiriyah University, Ministry of Higher Education and Scientific Research, Baghdad, Iraq.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/31460
Editor(s):
(1) José M. Garrido-Balsells, Department of Communications Engineering, University of Malaga, Spain.
Reviewers:
(1) Raúl Arasa Agudo, Meteosim S.L., Barcelona, Spain.
(2) Isidro A. Pérez, University of Valladolid, Spain.
Complete Peer review History: http://www.sciencedomain.org/review-history/17674

Original Research Article

Received 6th January 2017
Accepted 25th January 2017
Published 30th January 2017

ABSTRACT

Based on diurnal horizontal visibility and wind speed, three dust storms types and non-dusty days are identified in spring and summer seasons during 2005-2013 for Baghdad city to evaluate the impact of dust storm (DS) intensity on some meteorological elements and aerosol optical properties (AOP). The frequency of westerly and northwesterly winds increases significantly in three DS type days. The mean air temperature have (lower/higher) values in DS days during the (day/night) than non-dusty days while the relative humidity values have opposite phase. The maximum difference in air temperature and relative humidity in dusty days from its values in non-dusty days is higher in severe DS than in moderate and light DS at night time. The solar radiation has very good correlations with dust particles during the daytime where the high percentage of reduction of solar radiation in severe DS is about (45%) while reductions is about 32% in moderate DS and 23% in light DS. The variations in AOP are proportional to intensity of the DS. Increase in aerosol absorption optical depth (AAOD), aerosol extinction optical depth (AOD) at 388 nm and 500 nm

**Corresponding author: E-mail: sadia_alhassan@yahoo.com;*

and aerosol index (AI) while for aerosol single scattering albedo (SSA) show decrease during dust storm that means the process of aerosols absorption is more active than scattering during DS. This paper is interesting and the presented results may be particularly useful in the development of optical communication systems in the studied area.

Keywords: Dust storm; horizontal visibility; meteorological elements; solar radiation; aerosol optical properties.

1. INTRODUCTION

Dust storm is a significant environmental problem. It is play an influential role in climatology over Baghdad city which is like the rest of Iraq by suffering a significant increase in dust storms (DS) in the last decade. Mineral dust is generated by wind erosion over arid or semiarid land surfaces and is transported locally and over vast distances, causing adverse environmental and weather problems over broad areas. Dust particles reduce visibility and degrade air quality. As one of the major components of natural aerosols, dust modifies the radiation budget directly by influencing solar and infrared radiation and indirectly by modifying cloud properties [1]. Absorption and scattering of solar radiance cause by dust loading affects air temperature, cloud shape and air transmission [2]. According to WMO, World Meteorological Organization protocol dust storm is type of dust event that is result of turbulent winds and contain large desert soil particle and reduced visibility under 1 km [2,3,4]. Radiative forcing by dust particles can lead to either heating or cooling of the climate system depending on their single scattering albedo and the underlying surface albedo [5,6]. The Middle East shows a complex mixture of natural and anthropogenic sources. Mesopotamia has a frequency of occurrence of dust optical depth > 0.2 of more than 20% over most of the area. The region was described as a major source of dust since the 1980s [7]. The dust from the region between the Tigris and Euphrates is mostly natural in Iraq. Al-Najem [8] found two regions stricken by DS, one is centered over Baghdad and the other is centered west of Basra, as well as the Southern Desert being the major dust source while Northern Desert playing a secondary role. Wilderson, [9] surveyed dust and sand storm forecasting in Iraq and adjoining countries. There are three main DS types are found: shamal, frontal, and convective. Shamal DS is the most common type across the Middle East. The term “Shamal” means north in Arabic and refers to the prevailing wind direction from which this type of DS is produced [7]. Shamal DS occur across Iraq passing through Baghdad, Kuwait, and the Arabian Peninsula. In addition, the influence of meteorological regimes on dust storms is complex, which is also a key issue when studying dust. DSs differ in size, duration, and intensity, and previous studies on wind erosion have suggested that the prevailing meteorological conditions play a major role in determining these differences between DSs [10]. These characteristics are also helpful for DS identification. As pointed out by Shao et al. [10], the friction velocity which is determined by the surface wind speed and land surface conditions, is the key factor in regulating dust emission. The intensity of DSs is primarily influenced by the surface wind, resulting from the prevailing weather systems. Therefore, classification of DSs based on group characteristics and prevailing weather systems is valuable for dust identification and modeling studies [11]. Novlan, Huang et al., Extröm, [12,13,14] classified DS according to horizontal visibility in DS time as a DS severity index.

In the present study the three type DSs and corresponding non-dusty days are identified based on Iraqi meteorological organization and seismology (IMOS) data include horizontal visibility, wind speed and current weather (ww) and past weather (w_1w_2). DSs and non-dusty days occurred in the spring and summer months during 2005 to 2013 over Baghdad are selected. Aerosol optical properties derived from Ozone Monitoring Instrument (OMI) on board Aura satellite data are used. This study is focused on evaluated the impact of intensity of DSs on diurnal weather elements and solar radiation and daily OMI/Aura aerosol optical properties during the selected DSs/non-dusty days.

2. MATERIALS AND METHODS

2.1 Data Sources

Diurnal meteorological elements are collected from IMOS measurements at Baghdad station (latitude 32º 14'' N, longitude 44º 14'' E and elevation 31.7 m) (see Fig. 1) in the spring and summer seasons during the last decade (2005–2013). The meteorological elements in this work included the hourly data of surface levels visibility (km), wind speed (m s^{-1}), wind direction (deg), air temperature (°C), relative humidity (%), current weather (ww) and past weather (w_1w_2). Diurnal solar radiation data (W m^{-2}) measured by the automatic weather station (DAVIS, USA). It is installed at height of 18 m on the roof of the department of atmospheric Science, College of Sciences, Al-Mustansiriyah University in Baghdad city. Aerosol optical absorption depth (AAOD), aerosol single scattering albedo (SSA), aerosol optical extinction depth (AOD) at near-UV/Visible wavelength 388 nm and 500 nm and aerosol index (AI) on daily basis is used in this study. The data are retrieved from OMI on board AURA with spatial resolution 1° X 1° which are available at Giovanni web tool http://giovanni.sci.gsfc.nasa.gov/giovanni/.

2.2 Methods

DS/non dusty cases were identified according to the meteorological observation arrangement provided by IMOS. DS is inferred in terms of both horizontal visibility (vv) and wind speed (ff) at a specific location. DSs over Baghdad can be classified into three categories depended on horizontal visibility and wind speed as shown in Table 1. The process to identify DS cases is described by select the day when horizontal visibility is less than 1 km, wind speed is larger than 15 knots (8 m s^{-1}) and there is no rainfall that is considered as a dust storm day. According to Table 1 dust storms intensity is identified when minimum hourly visibility has been reached at that day and wind speed must exceed 8 m s^{-1}. Four times of observation is choice for selected DS days.

Non-dusty days are determined as the days before or after the selected dust storm day and must satisfy the following conditions that there is no rainfall and the horizontal visibility is equal to 10 km in whole day. Table 2 shows the selected cases used in this study. The dust storm/non-dusty days were chosen in case of availability of data of OMI/Aura aerosol optical properties over Baghdad city.

The wind rose is graphically method presenting the wind conditions, direction and speed, over a period of time at a specific location. In the present study the average of wind direction (dd)

Fig. 1. Baghdad station on Iraq topography map

Table 1. Classification of dust storms types and non-dusty days (based on IMOS data)

Dust storm type	Horizontal visibility (km)	Wind speed (m s^{-1})
Severe	$0 \leq vv \leq 0.2$	$8 < ff \leq 18$
Moderate	$0.2 < vv \leq 0.5$	$8 < ff \leq 12$
Light	$0.5 < vv < 1$	$8 < ff \leq 10$
Non dusty	vv =10	$ff \geq 0$

and wind speed (ff) data for Baghdad station during selected dust storms/non-dusty days were collected. These data were plotted by using Origin software to create wind rose and to determine the percentage of time that the wind was blowing from each direction.

The average, equation (1) and standard deviation, equation (2) are applied on the diurnal meteorological elements values such as air temperature (T), relative humidity (RH) and solar radiation.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{N} x_i \quad (1)$$

$$S = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \quad (2)$$

where n=sample size, $\bar{x}$=sample mean, S=sample standard deviation [15].

3. RESULTS AND DISCUSSION

3.1 Analysis of Horizontal Visibility

By using horizontal visibility for every 6 hours periods and minimum value of visibility reached at that day for Baghdad station were used to identify precisely dusty/non-dusty days. From Table 2 the mean daily horizontal visibility for different intensity of dust storms are 2.6 km (6.3/0.7/0.4/3.2 km) for severe DS days, 4.2 km (8/4/0.53/4.4 km) for moderate DS days and 4.5 km (8.6/2.1/1.9/5.2 km) for light DS days that indicate a direct proportional of the horizontal visibility with the intensity of DS. For non-dusty days the horizontal visibility was 10 km during the entire days.

3.2 Analysis of Wind Speed and Direction

Wind speed and its direction are analyzed to reveal the difference in the dominant hourly wind directions among the types of three DS and non-dusty days by using graphic tool of wind rose. Wind roses displayed in Fig. 2 show the winds during three type DS and corresponding non-dusty days at Baghdad station. The speed is higher in dust storms days than in corresponding non-dusty days and the west and northwest are dominant directions.

During severe DS days the wind is blow from the west (W) and northwest (NW) as shown in Fig. 2a with average wind speed to be around 6.7 and 7.8 m s^{-1}, respectively. The 2 spokes comprise 50% of all hourly wind directions where westerly wind was dominant that includes 32% of the time and northwesterly wind is about 18% of all hourly wind directions. The maximum speed at Baghdad station is 18 m s^{-1} blow from west direction. In Fig. 2b the wind directions in corresponding non-dusty days are in west, northwest and north (W, NW and N) directions and include 36%, 23% and 34% of all hourly wind directions, respectively. West and northwest (W and NW) wind directions in moderate DS days are dominant at most hourly wind direction with average wind speed to be around 5.8, 5.9 m/s, respectively and the maximum wind speed is 11 m s^{-1} which is blown from west direction. The 2 spokes around these directions in Fig. 2c comprise 50% and 28% of all hourly wind directions respectively, while in Fig. 2d the prevailing wind directions in non-dusty days are northwest and west directions that cover 43% and 25% respectively.

Table 2. Classification of dust storms based on horizontal visibility, wind speed, Note: Severe Dust Storm (SDS), Moderate Dust Storm (MDS) and Light Dust Storm (LDS)

Dust storm type	Dust storm days	H. visibility (km) at time (00/06/12/18)	Min H. visibility (km)	Non-dusty days	H. visibility (km) at time (00/06/12/18)
SDS	7-Jun-08	4/0.7/0.1/10	0.1	13-Jun-08	10/10/10/10
	17-Jun-09	3/0.5/0.5/0.2	0.2	3-Jun-09	10/10/10/10
	21-Apr-11	10/1.5/0.8/1.5	0.1	24-Apr-11	10/10/10/10
	22-May-12	8/0.1/0.2/1.2	0.1	16-May-12	10/10/10/10
MDS	9-Jun-08	2/1/0.4/0.4	0.3	20-Jun-08	10/10/10/10
	1-May-09	10/1/0.6/6	0.5	11-May-09	10/10/10/10
	27-Jul-10	10/6/0.7/10	0.4	19-Jul-10	10/10/10/10
	23-Mar-13	10/8/0.4/1	0.4	25-Mar-13	10/10/10/10
LDS	4-Jun-05	10/2.5/0.8/10	0.6	29-Jun-05	10/10/10/10
	8-Jul-08	6/3/2/3	0.7	11-Jul-08	10/10/10/10
	2-Jul-09	10/0.7/3/2.5	0.7	26-Jul-09	10/10/10/10

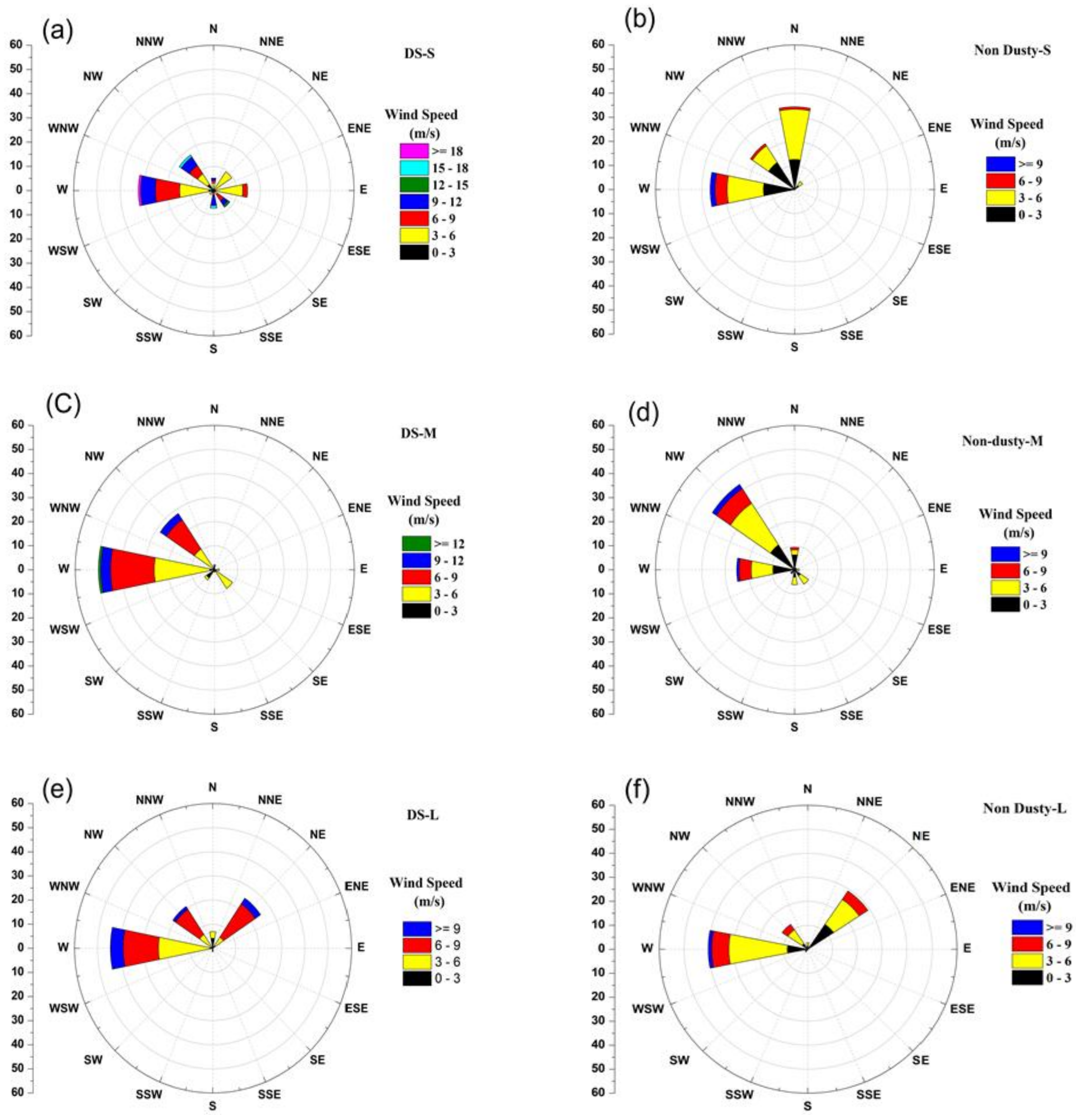

Fig. 2. Distribution of hourly means of the wind speed and its direction in days of (a) severe dust storm, (c) moderate dust storm and (e) light dust storm and their corresponding non dusty days in (b), (d) and (f)

In light DS days, the westerly direction (W) of wind is more dominant and other prevailing wind directions are northeast and northwest (NE and NW) as shown in Fig. 2e with the average wind speed to be around 5.6, 6.3 and 6.7 m/s, respectively. The 3 spokes around these directions comprise 44%, 25% and 21% of all hourly wind directions respectively, while in non-dusty days are the same directions (W, NE and NW) but with frequency (40%, 29% and 13%) of all hourly wind directions as shown in Fig. 2f. The maximum speed in light DS days is 10 m s^{-1} from west direction.

Therefore the wind directions are often associated with westerly and northwesterly winds. It can be seen that Baghdad city is located in sedimentary plain on both sides of the Tigris River at 40 miles from the Euphrates River and in a transition of Shamal wind. Shamal winds transport aerosols particles from their sources in Jordan, Syria and northwestern part of Iraq passing through Baghdad to the south and south eastern regions towards the Arabian Gulf.

3.3 Analysis of Air Temperature

Fig. 3 shows the variations of air temperature at Baghdad station for the different dust storms with corresponding non-dusty days. The air temperature is low during the daytime at three dust storms types and high during the night while in non-dusty days is high during the daytime and low at the night. Drop in air temperature is response to the diminished sunlight. The maximum difference in air temperature 6.1°C reached at 01:00 UTC for severe dust storm in Fig. 3a, 4.3°C at 00:00 UTC for moderate dust storm in Fig. 3b and 5.2°C at 02:00 UTC for light dust storm in Fig. 3c.

To see the extend variations in air temperatures for each hour we plot vertical bars at each point which represent standard deviations of air temperature values at that hour. The variations in air temperature values are found to be high in moderate and severe dust storm days. The reason is due to extreme values of air temperature resulting from the frequency of dust storms and high variation in spring and summer months. This variation also has good relation with intensity of dust storms.

3.4 Analysis of Relative Humidity

In Fig. 4 the mean relative humidity shows an opposite phase to air temperature. It has low values throughout the day and high values during the night. The relative humidity in three types of dust storms is lower during the night than in non-dusty days and is high in the daytime, except for light dust storm is higher in non-dusty day than in dusty days in day and night time owing to the selected light dust storm days are in summer month only.

Maximum difference of relative humidity has reached 19.8% at 01:00 UTC for severe dust storm, 17.8% at 00:00 UTC for moderate dust storm and 19% at 03:00 UTC for light dust storm from their values in non-dusty days. Again the variations in the local values of relative humidity are represented by vertical bars as shown in Fig. 4 are largest in severe and moderate dust storms (Fig. 4a and Fig. 4b) while they are lowest through light dust storm as illustrated in Fig. 4c.

3.5 Analysis of Solar Radiation

The diurnal variations of average solar radiation fluxes (W m^{-2}) during selected dust

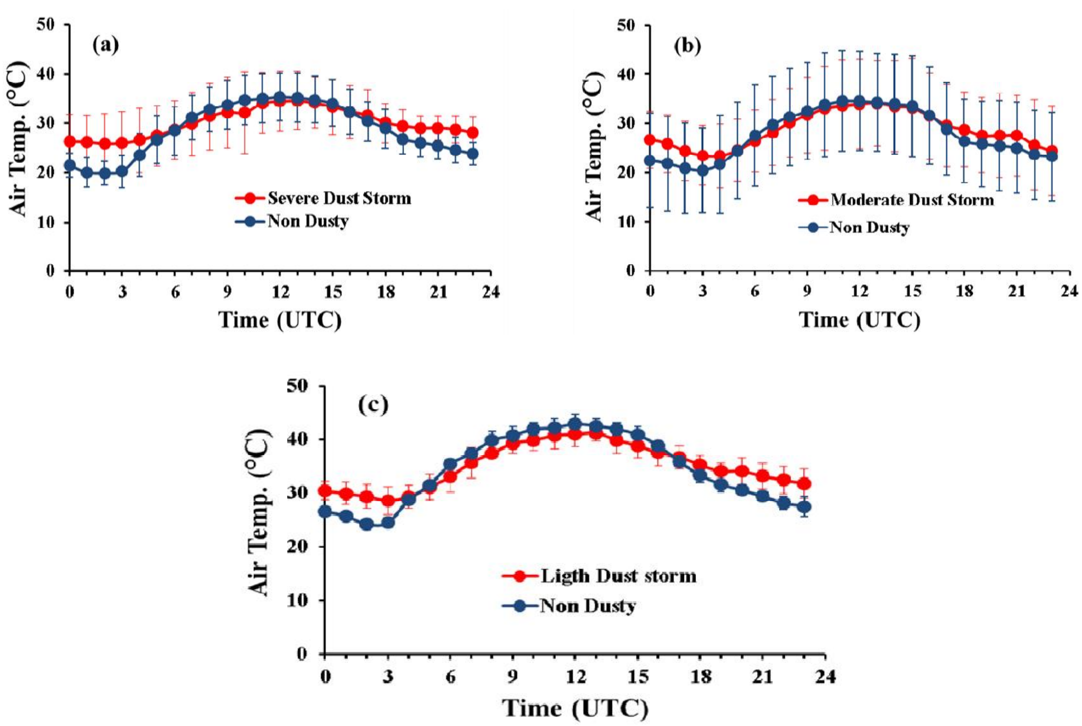

Fig. 3. Hourly mean of air temperature during days of (a) severe dust storm (b) moderate dust storm (c) light dust storm with their corresponding non-dusty days

storms/non-dusty days during the period (2005-2013) as showed in Fig. 5. It should be seen that the high deviation from the mean values of solar radiation for hours before the noon in the severe dusty days. This is the evidence that the dust particles can reduce the sun rays from reaching to the earth's surface. The reduction magnitude can be approximately estimated as follows: during the daytime, the solar radiation in three types of dust storm days is less than that in non-dusty days where in severe DS days the solar radiation have the largest difference of 498.3 W m^{-2} at 1300 UTC as shown in Fig. 5a while the difference in moderate and light dust storm days with non-dusty days are 349.3 W m^{-2} at 1400 UTC in (Fig. 5b) and 259 W m^{-2} at 1300 UTC in Fig. 5c, respectively. It appears that dust aerosols suspending in the air reduce the solar radiation amounts that reaches the land surface with values shown in Table 3 where the high percentage of reduction of solar radiation in severe DS is about to half (45%) while reductions is about 32% in moderate DS and 23% in light DS.

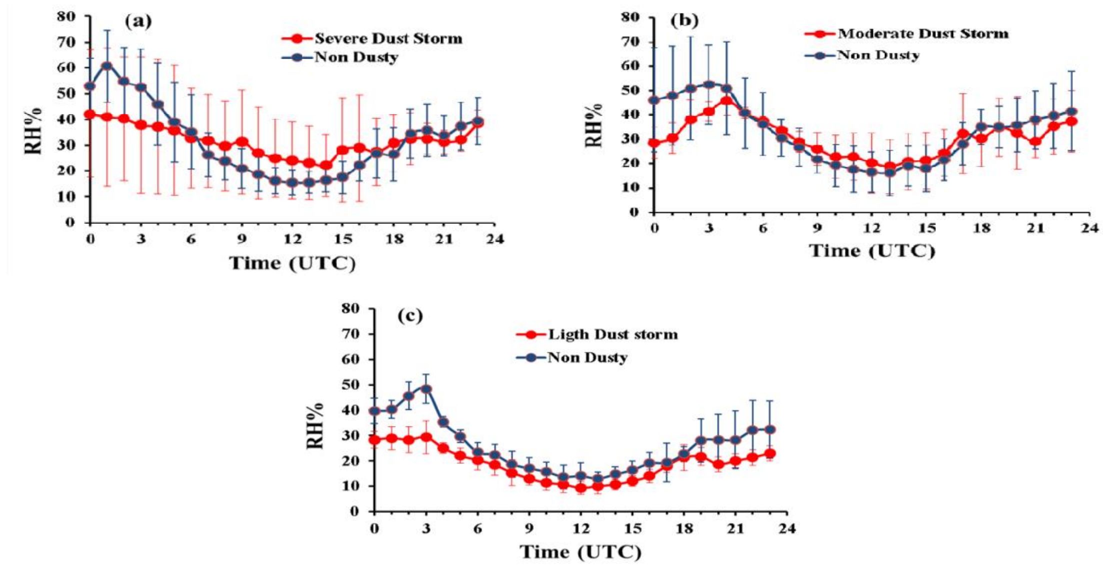

Fig. 4. Hourly mean of RH% during days of (a) severe dust storm (b) moderate dust storm (c) light dust storm with their corresponding non-dusty days

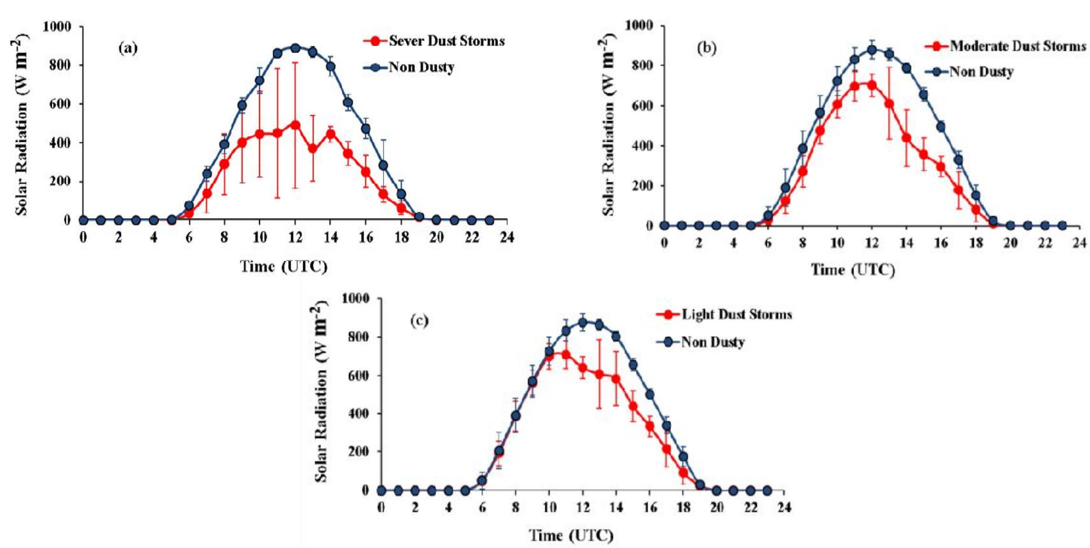

Fig. 5. Hourly mean of solar radiation during days of (a) strong, (b) moderate, (c) light dust storms with corresponding non-dusty days

Table 3. Percentage of solar radiation reduction during three dust storm types

Dust storm type	Max. percentage of reduction
Severe	45%
Moderate	32%
Light	23%

3.6 Analysis of Aerosol Optical Properties

Significant changes in aerosol optical properties such as AAOD, AOD, SSA and AI during the dust storms days are shown in Table 4. The AAOD, AOD and AI are higher during dust storms days than non-dusty days according to intensity of dust storm while SSA is found opposite to other properties. AAOD and AOD show enhanced values at 388 nm more than at 500 nm while SSA shows decrease values in DS than in non-dusty days and is high at 500 nm more than at 388 nm.

On average of three dust storm types, the mean of AAOD-388/AAOD-500 is 0.21/0.13 for dust storm days and 0.04/0.03 for non-dusty days. The AAOD-388 is high than AAOD-500 indicates to abundance of fine absorbing dust aerosols more than coarse aerosols in dusty days and they are higher than values in non-dusty days. This suggested that dust storms covered Baghdad city with finer particles from sedimentary plain.

In selected cases the mean SSA-388/SSA-500 is 0.90/0.92 for all DS days and is 0.95/0.95 for non-dusty days. AOD-388/AOD-500 mean is 1.84/1.31 for DS days and is 0.57/0.39 for non-dusty days that suggested total attenuation of aerosols by absorbing and scattering is high in dusty days than in non-dusty days. AI is a qualitive indicator for abundance of absorbing aerosols. It’s found that AI in DS days is higher than in non-dusty days where the mean of AI in DS /non-dusty days is 3.45/1.42. It can be concluded that more absorbing aerosols are existent in the air during dust events than during non-dusty days. From Fig. 6, the aerosol optical properties show percentage increase during dust storms according to intensity of the DS for each property AAOD, AOD and AI while for SSA show percentage decrease with intensity dust storm. The high and low increase in aerosol properties is 50%, 10% occurred in AOD-388 in severe and light DS respectively.

Table 4. Mean of daily aerosol optical properties during selected dust storms and non-dusty days

Days type	AAOD-388	AAOD-500	AOD-388	AOD-500	SSA-388	SSA-500	AI
Severe dust storms	0.26	0.18	2.34	1.60	0.90	0.90	3.69
Non dusty	0.05	0.03	0.58	0.38	0.93	0.93	1.49
Moderate dust storms	0.20	0.13	1.93	1.39	0.91	0.93	3.40
Non dusty	0.03	0.02	0.47	0.33	0.96	0.96	1.23
Light dust storms	0.14	0.07	1.04	0.82	0.90	0.93	3.23
Non dusty	0.04	0.02	0.70	0.51	0.95	0.96	1.59

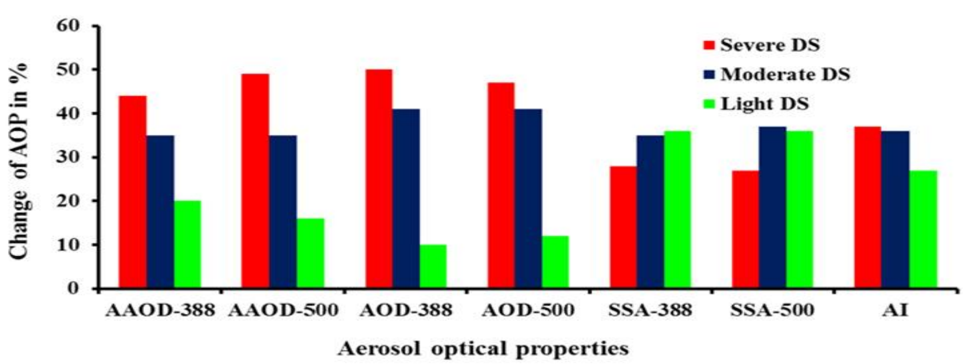

Fig. 6. Percentage change of AOP during different intensity dust storms from non-dusty days

4. CONCLUSION

Measurements of diurnal meteorological elements and daily OMI/Aura aerosol optical properties during 2005–2013 have been analyzed to study the impact of dust aerosols during three types of dust storm and non-dusty days over Baghdad city. From the analysis of the selected cases it's found that:

1. During dusty days, the wind directions are often associated with westerly and northwesterly winds.
2. The mean air temperature have (lower/ higher) values in DS days during the (day/night) than non-dusty days while the relative humidity values have opposite phase. The maximum difference in air temperature and relative humidity in dusty days from its values in non-dusty days is higher in severe DS than in moderate and light DS at night time.
3. The solar radiation has very good correlation with dust particles during the daytime where the high percentage of reduction of solar radiation in severe DS is about (45%) while reductions are about 32% in moderate DS and 23% in light DS.
4. AAOD, AOD and AI show percentage increase according to intensity of the DS that indicate to abundance of absorbing aerosols and fine aerosols than coarse aerosols in DS days while SSA shows percentage decrease with intensity dust storm that conclude the process of aerosols absorption is more active than scattering during dust storms.

ACKNOWLEDGEMENTS

The authors would like to thank Iraqi meteorological organization and seismology, Climate Department staff for their valuable help and support meteorological data. Also authors thank NASA Giovanni, GES DISC User Service staff for their supporting online data.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Liu M, Westphal DL, Walker AL, Holt TR, Richardson KA, Miller SD. COAMPS real-time dust storm forecasting during operation Iraqi Freedom. Weather and Forecasting. 2007;22(1):192-206.
2. Goudie Andrew S. Dust storms: Recent developments. Journal of Environmental Management. 2009;90(1):89-94.
3. Shao Y, Dong CH. A review on East Asian dust storm climate, modelling and monitoring. Global and Planetary Change. 2006;52(1):1-22.
4. McTainsh GH, Pitblado JR. Dust storms and related phenomena measured from meteorological records in Australia. Earth Surface Processes and Landforms. 1987; 12(4):415-424.
5. Tegen I, Lacis AA. Modeling of particle size distribution and its influence on the radiative properties of mineral dust aerosol. Journal of Geophysical Research-All Series. 1996;101:19-237.
6. Haywood J, Boucher O. Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: A review. Reviews of Geophysics. 2000;38(4):513-543.
7. Middleton NJ. A geography of dust storms in South-west Asia. Journal of Climatology. 1986;6(2):183-196.
8. Al-Najem F. Dust storms in Iraq. Bulletin of the College of Science, University of Baghdad. 1975;16(2):437-451.
9. Wilderson WD. Dust and sand forecasting in Iraq and adjoining countries (No. AWS/TN--91/001). Air Weather Service Scott AFB IL; 1991.
10. Shao Y, Jung E, Leslie LM. Numerical prediction of northeast Asian dust storms using an integrated wind erosion modeling system. Journal of Geophysical Research: Atmospheres. 2002;107:D24.
11. Lei H, Wang JXL. Observed characteristics of dust storm events over the western United States using meteorological, satellite, and air quality measurements. Atmospheric Chemistry and Physics. 2014; 14(15):7847-7857.
12. Novlan DJ, Hardiman M, Gill TE. A synoptic climatology of blowing dust events in El Paso, Texas from 1932-2005. In Preprints, 16th Conference on Applied Climatology, American Meteorological Society. 2007;3:12-13.
13. Huang M, Peng G, Zhang J, Zhang S. Application of artificial neural networks to

the prediction of dust storms in Northwest China. Global and Planetary Change. 2006;52(1):216-224.
14. Ekström M, McTainsh GH, Chappell A. Australian dust storms: Temporal trends and relationships with synoptic pressure distributions (1960–99). International Journal of Climatology. 2004;24(12):1581-1599.
15. Church JA, White NJ. Sea-level rise from the late 19th to the early 21st century. Surveys in Geophysics. 2011;32:585-602.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17674