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Monitoring Dust Storms over Iraq Using Satellite Images a Case Study

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Abstract: During dust storms, normally considered to be natural hazards, the dust aerosol is loaded into the atmosphere. The present study addresses a dust storm event and its transport, occurred from 27 October-5 November 2017 with the strongest intensity on 28-30 October, using the satellite-borne sensors, namely the Moderate Resolution Imaging Spectroradiometer (MODIS) aqua, NOAA/ESRL Physical Science Division (PSD) maps and weather underground data to investigate the spatial and temporal variations of Aerosol Optical Depths (AOD) over Iraq. The satellite observations shows the transport of AOD from Syria desert to Northern and central of Iraq and from Northern Peninsula Arabian desert to Southern and central regions due to the Sharki and Shamal winds activities. The highest winds were on 27-30 October and 3-4 November and highest AOD occurred in 30 October, particularly over Baghdad and Al Salman was 2.3 and 2.26, respectively. The impact of the dust storm on the central and Southern regions was more pronounced. The sharp reduction in horizontal visibility, associated with strong wind gust in the vicinity of leading edge of the front was very low (<3.4 km at Mosul and 2 km at Baghdad and Basrah). This study sheds new light on the processes responsible for dust transport and emission over Iraq in connection with winds strong events. Enhanced information for these processes is a key to developing the dust forecast in this region.

Key words: Dust, AIRS, MODIS, Iraq, dust, region

INTRODUCTION

The desert dust is one of the most abundant and significant aerosols in the atmosphere. Dust storms have an impact on public health and both airborne and surface traffic (Miri *et al.*, 2007; Furman, 2003). It poses natural hazards in the Middle East region and serious environmental problems in South-West Asian (Hamidi *et al.*, 2013; Carboni *et al.*, 2012). This area is prone to dust storms originating from both active internal dust sources and external dust source regions (Prospero *et al.*, 2002). The dust storms are particularly active during Summer in Middle East and in Southwest Asia due to the strong Northwesterly winds known as "shamal winds". It also observed during Winter (Middleton, 1986a, b). The Winter Shamal occurs as frequently as two to three times per month while a Summer Shamal event blows practically continuously (Vishkaee *et al.*, 2012).

During last 10 years, the Iraqi Meteorological Organization and Seismology reported number of rising dust days per annum an average of 30+ in Baghdad, 45+ in Basrah and 7+ in Mosul. In addition, there is a reduction in visibility below 3 km between 5 and 10% during Winter. The Tigris-Euphrates alluvial plain is known as the main dust source in the Middle East. The dust particles of this area mainly consist of fine sediments from these two rivers. Therefore, it can be transported over large distances and have important impacts on the neighboring countries. Due to the development of the dam construction projects on Tigris and Euphrates Rivers which decrease the humidity and water content of soil in the downstream areas, the dust activities have intensified in the Mesopotamian area in recent years (Hamidi *et al.*, 2013).

Atmospheric dynamics, e.g., hurricanes and hurricanes are mightily associated to the aerosol properties and loading in the atmosphere can cause dust transport and emission during their occurrences (Badarinath *et al.*, 2010). The certain criteria in the atmospheric should be met before dust can be lifted (Kalu, 1979). Many factors affect the dust storms not only the wind. The upward vertical motion and some sort of turbulence must be exist to extract the particles away from the desert surface. Also, the ground should be dry enough to allow the dust to be lifted. The abundances of

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the atmosphere parameters, last few decades, measured by different sources from sparsely distributed stations, Balloons and airplanes. These ground based observations represent point measurements and more sensitive to sources and sinks with best accuracy. Nevertheless required expensive software or permanent automatic monitoring stations and not able to make continuous daily global variations evaluation (Rajab *et al*., 2010).

Only the observations by satellite remote sensing from the space allow for such measurements and increase our ability to analysis the abundances of atmosphere gases and parameters (Lim *et al*., 2008; Rajab *et al*., 2014). Many researchers has reporting the use of satellite measurements to investigate the indirect impacts of temporal and spatial patterns of aerosols, at both global and regional scales (Jafari and Malekian, 2015; Fadnavis *et al*., 2012; Alam *et al*., 2011; Matheson *et al*., 2005). Satellite remote sensing is an essential tool for observing the radiative effects of aerosols on climate and the global aerosol budget (Tripathi *et al*., 2005; Penner *et al*., 1992). Satellite remote sensing allows synoptic and complete mapping of a large area in a single snapshot and it also has the major benefit of allowing assessing the spatial distribution and properties of aerosols (Kosmopoulos *et al*., 2008).

In this study, we shed new light on the processes responsible for dust transport and emission over Iraq in coincide with gale force winds and turbulence at the leading edge of the Shamal. The MODIS aqua, NOAA/ESRL (Earth System Research Laboratory) Physical Science Division (PSD) and weather underground data for Iraq was employed to investigate the Aerosol Optical Depth (AOD) retrievals emission and transport. During 20 October-10 November 2017, intensive dust event took place in Iraq with the strongest intensity on 28-31 October, releasing huge amounts of aerosols (dust) into the atmosphere. The dust storm associated high winds reduced the air quality highly, causing reduced visibility due to increased aerosol burden. The dust drifted long distances with air masses. The role of winds on dust emission and sharp reduction in surface visibility are also highlighted. The key of improving the dust forecasts is enhanced knowledge of these processes in this region.

MATERIALS AND METHODS

Study area and meteorological characteristics: Iraq has a wide variety of natural resources: high mountains in the North and Northeast are home of forests which is considered the most favorable for rainfall and is used for agriculture. Alluvial plain in central and Southeast sections, rolling upland between upper Tigris and Euphrates rivers and desert in West and Southwest. In the extreme South of the country, Basrah is a harbour city in the North Mosul is a commercial and agricultural city and Baghdad the business and industrial capital of Iraq (Fig. 1).

The topographic variation makes Iraq geographically unique for any study of spatio-temeporal patterns. Altitudes within Iraq range from sea level (i.e., the Arab Gulf) to the highest peaks of the mountains at Northern parts (3,611 m (11,847 ft)). Desert regions at South and west constitute half of Iraq. The two major rivers flowing from Northwest to Southeast are fertile alluvial plains covers 19,425 km^2 of marshland at Southeastern of Iraq (US. and MCIA., 1998). Data for five selected distinct cities in Iraq (Fig. 1) have been analyzed and the variations in aerosol concentrations investigated. The Baghdad, Mosul and Basrah cities comprise major urban centers of Iraq with generally dense populations and varied distribution patterns for residential, industrial and commercial land use areas.

The Middle East climate is mainly affected by four systems: The Polar anticyclone over east of Europe and Mediterranean Sea in Summer, The Siberian anticyclone over central Asia in Winter, The depressions travelling from East of Mediterranean Sea and North of Africa and South across the Middle East and Southwest of Asia in the nonsummer seasons, The monsoon cyclones over the South and Southeast of Iran, India subcontinent and Southeast of Arabian Peninsula in Summer. In Iraq, more than a third of all instances of blowing dust causes by the Kaus and Sharki winds Easterly to Southerly are the favored directions from October to April (Hamidi *et al*., 2013).

The Iraqi climate is subtropical, continental and semi-arid; mostly have a hot arid climate with subtropical

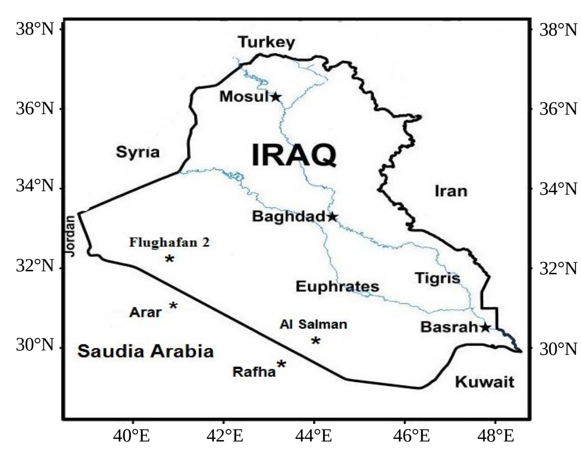

Fig. 1: Map of study area

influence. The Winter is cool season and its temperatures 2°C night-time and infrequently exceed 21°C. The mountain regions (North and Northeast) are having a Mediterranean climate and colder with heavy snows, sometimes causing extensive flooding. The mean annual rainfall 216 mm and most regions receive <250 mm and maximum rainfall happen during Winter and it's extremely rare during the Summer. The Summer is dry and hot season, most parts have temperature average above 40°C daytimes and drops to 26°C at nights, frequently exceed 48°C. The Shamal winds prevailing during Summer months, it is steady wind and blows from North and Northeast (Frenken, 2009; Abed *et al*., 2017).

Datasets and analyses: This research has been carried out for 22 days data from 20 October to 10 November 2017. A variety of datasets have been used for this research. In order to evaluate and analysis the impacts of winds on the dust emission over the study area, we selected five stations dispersed across Iraq, Baghdad, Mosul, Basra, Flughafen 2 and Al Salman as shown in Table 1 and Fig. 1. The Deep blue AOD at 0.55 μ of land and ocean [(MYD08-D3) Version 6 mean] data from the MODIS sensors onboard aqua satellite were used to analyze and understand the variability of aerosols over different parts of Iraq. The NOAA/ESRL Physical Science Division (PSD) maps used to assess the impact of daily wind speed and surface lifted index on aerosols. In addition, weather underground data employed for wind speed and visibility to observe and analyze their distribution and its effect on the aerosols during the study period.

The MODIS-aqua is one of six earth-observing instruments measures radiances at 36 wavelengths from 0.41-14 μm aboard the aqua satellite launched in May 2002. MODIS provides daily near-global coverage and retrievals of AOD at several wavelengths over both ocean and land. Over ocean, seven wavelengths (0.47, 0.55, 0.66, 0.86, 1.2, 1.6 and 2.12 μm) are used to retrieve aerosol optical depth and other aerosol properties (Tanre *et al*., 1997). Over land, AOD is retrieved at 0.47, 0.55 and 0.66 μm (Kittaka *et al*., 2011). Aerosol retrievals are produced at a resolution of nominally 10×10 km^2 at nadir. A 2330 km viewing swath provides near-global coverage every day l (Redemann *et al*., 2012).

Table 1: Stations GMD

Name	Longitude	Latitude	Country
Baghdad	44.20	33.20	Iraq
Mosul	43.06	36.20	Iraq
Basra	47.50	30.20	Iraq
Samawa	45.18	31.18	Iraq
Flughafan 2	39.35	32.44	Iraq

RESULTS AND DISCUSSION

AOD concentrations: As the primary dust sources, the Tigris and Euphrates River alluvial plain caused nearly 60 major dust storms recorded between 2003 and 2011 and reported as natural hazards by MODIS as listed by NASA Earth Observatory (data available from http://earth observatory.nasa.gov/NaturalHazards). The satellite images for a certain date and time and is named natural hazard shows the worst situations of every dust storm (Hamidi *et al*., 2013). For this study, 7 days before and 7 days after the dust storm image and data were selected to identify and analysis the active days of dust emission. The NOAA/ESRL (PSD) data were used to study the meteorological conditions and to determine the 22 days wind velocity and surface lifted during the dust storms. The NOAA/ESRL (PSD) assimilated data are available from the NOAA website: http: //www.esrl.noaa.gov and utilized to identify the active days of dust emission.

In order to study the influence of winds convection on the distribution of aerosols daily mean concentrations of dust aerosols from the MODIS ensemble are analyzed during the 20 October to 10 November of the year 2017. Figure 2 shows the daily mean distributions of AOD 26 October-6 November. During 26-28 nothing to pronounced and normal except slight rise of aerosol over center areas (red pixels). In agreement with satellite observations MODIS images shows a layer of aerosols in the Northwest regions during 29-31 October and its influence extends to the central and Southern regions (Yellow pixels). Transport of boundary layer aerosols from Northwest area to the North and central of Iraq due to the Sharki convection is evident. High concentrations extend to the Southern regions associated with Shamal winds activity which carry appropriate amount of aerosols from Northern Arabian Peninsula desert.

This winds show a strong action between 29 October and 2 November. During 1-4 November, slight reduction in aerosols Bconcentrations in Northern regions with pronounced continued maximum in the central and Southern regions coupled with Shamal winds efficacy. The situation is normal with the calmness of the winds during 5-6 November (Pink pixels). There are two regions of horizontal AOD transports: first from Syrian Desert to Northern and central regions due to Sharki winds (Eastward) winds and second from Northern Arabian Peninsula desert to Southern and central regions due to Shamal (Northward) winds.

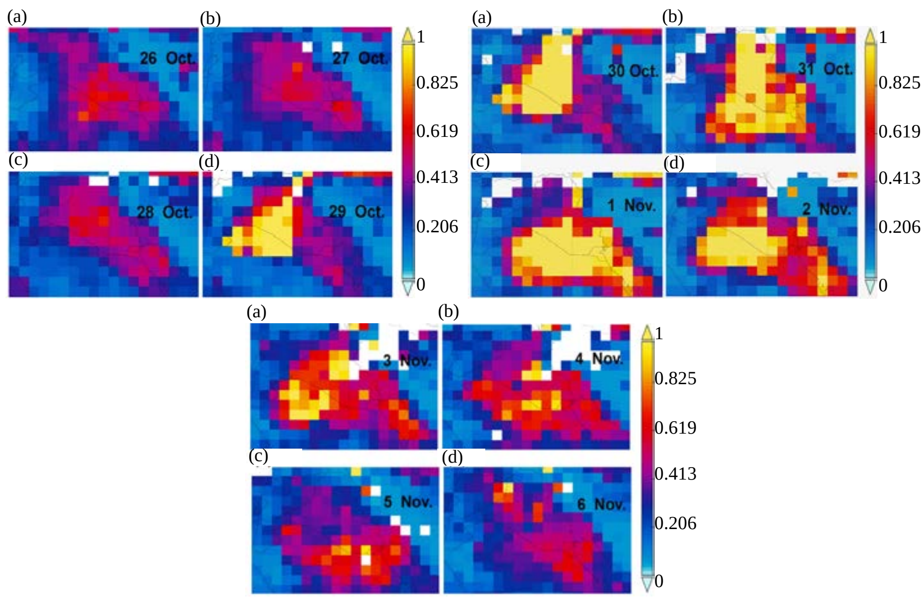

Fig. 2: Distribution of deep blue AOD (0.55 μ) main daily degree [MODIS-aqua MYD08-D3-V6] for the periods; a-d) Top left 26-29 October; a-d) Top right 30 October-2 November and a-d) Down 3-6 November

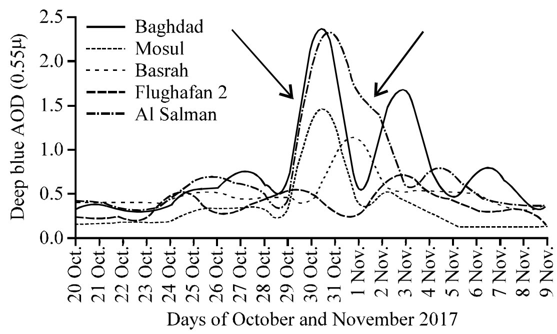

Fig. 3: Daily Deep Blue AOD (0.55 μ) distribution between 20 October and 10 November 2017 for the five stations Baghdad, Mosul, Basra, Flughafen 2 and Al Salman

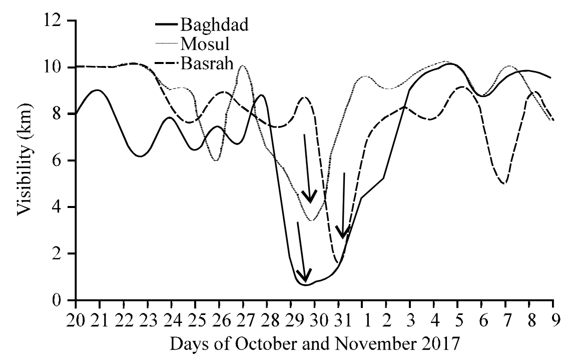

Fig. 4: Daily horizontal visibility (km) between 20 October and 10 November 2017 for the three stations Baghdad, Mosul and Basra

Daily variations in AOD were analyzed using MODIS data over a period of 21 days for five selected stations (Fig. 3). Our analysis showed that the highest AOD values were observed in 30 October, particularly over Baghdad and Al Salman was 2.3 and 2.26, respectively. As both stations are close to desert regions, dust aerosols were more persistent. Similar increases in aerosol concentrations were found for other stations. The AOD values started to increase from 24 October over all stations and reached a maximum in 30 and 31 October, except Flughafan 2 in 29 and 30 October. But that high AODs persisted over Baghdad till 4 November due to Shamal winds activity. It is important to emphasize that increases in the total AOD values for Iraq cities are due to a complex mixture of causes. The results indicate that aerosol concentrations increased with increased winds activities.

Visibility, wind surface and left surface related to the dust storms: The dust storms are considered to be associated with visibility values of 2 km or less (Fig. 4). This threshold value on visibility enables us to account for both the visibility resulting from long-range transports and strong events occurring over dust source regions in Iraq. At the other end of the spectrum, the representative of clean air conditions considered have visibility values above 10-12 km and the moderate pollution events visibility ranging from 3-10 km associated with more or less thick Aeolian dust plumes (Vishkaee *et al*., 2012). In the case of propagating dust storms, the arrival of airborne dust associated with a significant decrease in high wind speed and visibility at a given site. Because smog and fog reduce the visibility significantly in big cities (e.g., Baghdad), wind speed is an important criterion for segregating between dust storm events and smog/fog. So, we observed less visibility in Baghdad even in the days of the nonstormy (e.g., in 20-28 October).

The arrival of the cold front (winds) in Mosul and Baghdad occurs in 28 October (Fig. 5). The passage of the cold front is associated with a wind surge of 15 km and a decrease of visibility because the front encounter active dust source over Syria desert. A very sharp decrease of the visibility from 10-3.4 km at Mosul in 30 October is observed, following strong surface wind surges. This behavior is an indication of the arrival of the leading edge of a propagating dust storm. This decrease is not associated with light winds (20-27 October) (Fig. 4). Likewise, in Baghdad and Basrah (Fig. 4 and 5), a marked decrease of surface visibility to less 2 km occurs over Baghdad and Basrah during 29-31 October. The strongest wind surges are observed to be associated with the Kaus wind blowing ahead of the cold front (Shamal winds) (35 km) encounter dust source from Northern Arabian Peninsula desert.

In Baghdad and Basrah, the visibility is unaffected at the time of the wind surge likely means that no important surface dust load is transported by the leading edge of the Shamal winds (3-4 November) (Fig. 2-5). The decrease of the surface visibility is first observed to be associated with the Kaus wind at all stations and then a second decrease is observed in relationship with the Shamal. In Mosul the visibility increases slightly after the Kaus surge reaching 7.5 km in 2nd November. The dust mobilized at the leading edge of the front when passing over a dust source is trapped in the closed circulation behind the front. Therefore, it can be carried over large distances as long as the density difference across the front is important. The low visibility over the stations after the passage of the leading edge of the dust storm is likely due to the weak surface winds behind the front (Fig. 5 and 6) preventing the mobilized dust from adverting out.

Figure 6 shows the wind speed and direction over study area in 28-31 October and 3-4 November. A cold front (southeast) originating from the Turkish highlands passed over the Syrian desert on 28 October and triggered an intense dust storm on 29 and 30 October over Northern and progressively decreasing in magnitude and shifting to a Southerly flow over central and South Iraq. This associated with the strong Shamal (Northwest) winds caused the mobilization, lifting and long-range transport of aerosols from Northern Arabian Peninsula desert to Southern and central of Iraq in 31 October. Only the effect of the Northwest wind appears on the Southern regions in 3-4 November.

On the basis of the charts of mean potential left surface shown in Fig. 7, it appears that the cold front (Shamal) is oriented Northeasterly/Southwesterly and that it propagates eastward. This is confirmed by our analysis of the cold front crossing at each of the 5 stations considered in this study and other regions (Fig. 4-6). The strongest observed mean left surface are associated with the Northeasterly winds in 29-31 October.

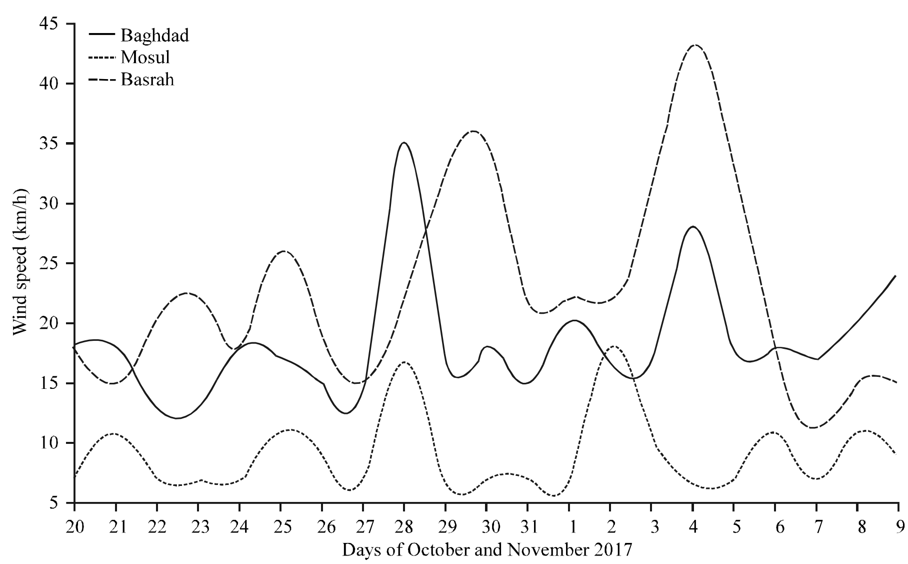

Fig. 5: Daily wind speed (km/h) between 20 October and 10 November 2017 for the three stations Baghdad, Mosul and Basra

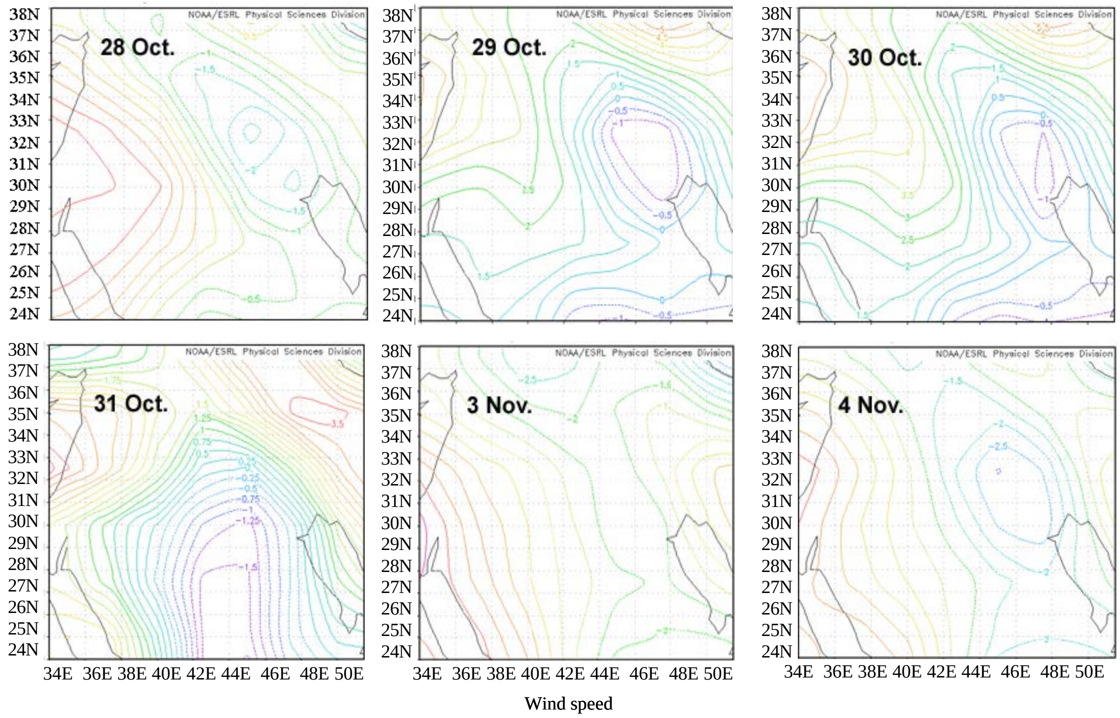

Fig. 6: Mean wind speed (m/sec) for the periods 28-31 October and 3-4 November 2017 covering the study area between longitude 34-51 E and latitude 24-38 N

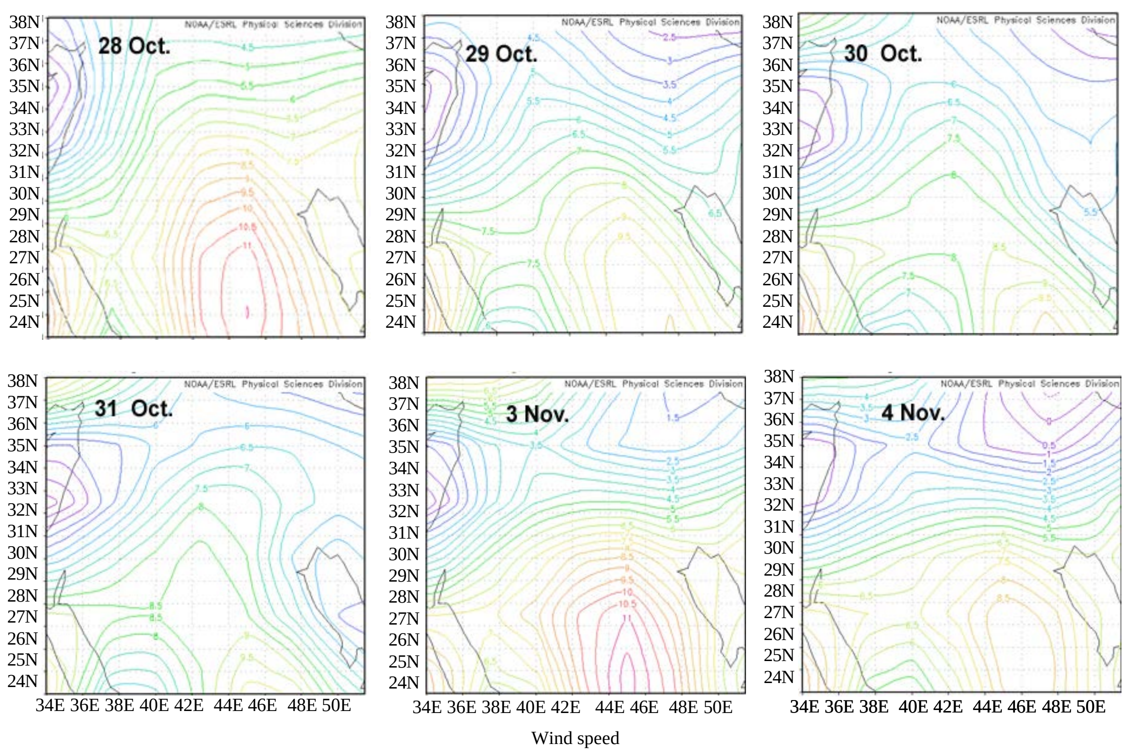

Fig. 7: Mean left surface (degree) for the periods 28-31 October and 3-4 November 2017 covering the study area between longitude 34-51 E and latitude 24-38 N

CONCLUSION

Transport of desert dust over Iraq associated with Shamal and Kaus winds has been studied using a suite of spaceborne remote sensing platforms (MODIS Aqua), NOAA/ESRL (PSD) and weather underground data. During the 28-31 October 2017 case, dust emission regions were located in Iraq. Emissions in Iraq occurred in response to strong Shamal and Kaus surge winds. The highest frequency of winds was on 27-30 October and 3-4 November. The MODIS observations shows transport of boundary layer aerosols from Syria desert to Northern and central of Iraq due to Sharki winds and from Northern Peninsula Arabian desert to Southern and central regions due to Shamal winds. To better assess the impact of daily AOD data, 5 stations selected and the analysis showed highest AOD occurred in 30 October, particularly over Baghdad and Al Salman was 2.3 and 2.26, respectively.

Surface measurements over Iraq provided evidence that the visibility, associated with dust lifting and transport by winds was very low (<3.4 km at Mosul and 2 km at Baghdad and Basrah) and could last for 1-3 days. The sharp reduction in horizontal visibility observed over Iraq happened after the passage of the cold front (15 km) and was associated with strong wind gust (Shamal winds, 35 km) in the vicinity of leading edge of the front. Shamal is the main type of Synoptic dust storms in this area. The highest frontal dust storm is on 28-31 October. This study shows that the Satellite observations (MODIS aqua) shed new light on the processes responsible for dust transport and emission over Iraq in connection with Shamal and Sharki winds events.

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