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Investigation of Severe Dust Storms Over Baghdad City by Using Remote Sensing Measurements and Ground Data

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Abstract. Dust aerosols have serious influences on different sectors such as the economy, climate change, pollution, transportation and public health. Dust storms have increased over the Middle East especially impacting central Iraq lately. The goal of the work is to identify possible dust sources and pathways influencing the study area. Using remote sensing data by employing the monthly average of Aerosol Index (AI-OMI), HYSPLIT model and MODIS satellite to examine potential dust storms sources and their transport pathways through spring season in 2012. The results of aerosol index (AI) values by OMI satellite were high during spring and summer but were low during autumn and winter. AI values are increased in the likely major dust sources including eastern parts of Syria, Kuwait, north Saudi Arabia, southwestern parts of Iran, as well as south and central parts of Iraq. Also, analyses of the HYSPLIT model show possible dust storms sources and predominate directions of dust which can reach Baghdad city including transported dust aerosols from the eastern region of Syria, north-western, western Iraq. The findings of pathways by the HYSPLIT model for possible dust sources are agreement with satellite images from MODIS – OMI satellites (dust storms are revealed by the MODIS – OMI satellites). The information of CALIPSO satellite revealed that the dust activity had reached 18 kilometres to the stratosphere layer. The HYSPLIT trajectories findings for dust storms travel are like to the image of the MODIS satellite.

Keywords. Dust Storms, Remote sensing, Pollution, Climate change, Aerosol Index (AI), OMI, CALIPSO Satellites, HYSPLIT Model.

1. Introduction

Dust aerosols mainly occur around arid areas in the globe, particularly in the spring season. Desert areas produce large mineral dust quantities to the atmosphere. Dust events have an important part in biogeochemical processes, the chemistry of the atmosphere, air quality, the environment and climate system at a global scale [1-6]. The dry and wet deposition process clear dust aerosols from the air. Whereas the deposition process of wet considers controlling through transfer process across oceans, the process of dry deposition clears large dust particles closes to dust source regions. Baghdad is the capital city of Iraq, and it represents one of the cities that expose to severe dust storms throughout the year, is influenced by major dust sources from the desert and semi-desert regions in the Middle East such as Iraq., Kuwait, ,Syria, Saudi Arabia, Iran Jordan, as well as Turkey, Baghdad city is remarkably

damaged via dust storms, transferred through dry prevailing surface winds (north western/Shamal winds) in springtime, these surface winds may transport dust particles amounts from the south part of Iraq [7-9]. Iraq represents a great concern of dust storms because it has wide desert regions which represent approximately 40% of the total area of Iraq Increase the desertification areas in Iraq because of several factors including an unsteady political situation, army operations and the many wars, bad use of lands and severe drought period since 1999 [7,10-12]. There are major methods to study dust storms in order to obtain dust source areas identification and pathways by using different developed methods including geological models, mineral detectors, remote sensing techniques, satellite images, meteorological data and dust measurements analysis, numerical simulations and dust particles path analysis [13-19].

In addition, to identify possible dust source areas, Aerosol Index (AI) values have taken from the -TOMS (Total Ozone Mapping Spectrometer) satellite on the platform of Nimbus 7 [10,14,17]. Aerosol index (AI-TOMS&OMI) values were derived from different sensors of Nimbus-7 (1979-1993), as well as Earth Probe (1996-present) by the TOMS (Total Ozone Mapping Spectrometer), and the Aura-OMI (Ozone Monitoring Instrument) (2004-present at wavelengths 360 and 331 [10]. Aerosols Index (AI) values represent dust, ash, volcanic and smoke over lands surface (desert, snow and ice-covered surfaces). Aerosol index concentrations can reveal absorbed aerosol from non-absorbed aerosols obviously because it is able to measure radiation absorption of UV via smoke and desert dust. UV-absorbed aerosols (positive values of AI) indicate mineral dust aerosols, ash, volcanic ash, and smoke. Whereas non-absorbed aerosols (negative values of AI) indicate sulfate and particles and sea salt from no crustal and natural sources [20]. AI values indicate cloud presence when almost equal to zero. Few studies about the determination of dust sources and pathways using remote sensing techniques in Iraq. According to the World Health Organisation, Bagdad city is one of the polluted cities on a global scale (WHO, 2006). Determination of dust sources and pathways, that cause dust events in Iraq, consider a significant issue.

The transport of aerosols towards East Asia, due to biomass burning in the south eastern part of Asia, can be traced using satellite remote sensing techniques. These include the Aqua/Terra sensors on MODIS (Moderate Resolution Imaging Spectroradiometer) satellites, and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) and as well as ground data such as AERONET (Aerosol Robotic Network) and MPLNET (Micro Pulse Lidar Network) by NASA agency [21].

The study aims to define potential dust sources and pathways transport which hit the central region of Iraq, particularly the capital city of Baghdad. The current work applied remote sensing techniques (HYSPLIT Model), a monthly average of Aerosol Index (AI), from Ozone Measurement Instrument (OMI) and MODIS (Moderate Resolution Imaging Spectroradiometer) satellite. This study can be used as a start point and a good approach to monitor and analysis dust storms around the world.

2. Study Region

Baghdad city is situated at latitude (33˚34') and longitude (44˚40') at elevation 41 m above sea level. This city covered 4555 km2 in central of Iraq with population 8,765,000 in 2016 according to Iraqi Ministry of Planning - Central Statistics Organization (CSO). The study region has selected to analyse severe dust storms during spring in 2012. The climate of Baghdad is extremely hot and dry in the summer season and cold and rainy in the winter season (Köppen climate classification). The average maximum temperature is as high as 44 °C in the summer season (June- August). The highest temperature reached about 51.8 °C was in Baghdad city on 28 July 2020. The minimum mean temperature in winter was about -2˚C (in January). Annual rainfall averages (rainfall season start from November to March) are approximately 150 mm. Baghdad city is influenced by northwest surface winds during most of the year. The humidity is less than 50% in the summer season because of Baghdad is situated far from the coasts of the Arabian Gulf and marshy southern Iraq. During the summer-spring seasons, dust storms from the desert regions to the west are a normal occurrence.

3. Datasets and Methodology

The monthly mean aerosol index (AI) data from the OMI satellite over Baghdad city (2004–2020) were obtained from the NASA agency (http://giova nni.gsfc.nasa.gov) to obtain the distribution of dust aerosols according to remote sensing data. AI values between 0 and 4 (refer to the presence of intense dust storms). Meteorological data [including relative humidity, temperature and rainfall)] were also collected from the Iraqi Meteorological Organization for the ground meteorological station of Baghdad during the study period.

The (HYSPLIT) (Hybrid Single-Particle Lagrangian Integrated Trajectory) model was employed to define dust activity the transport trajectories and sources by meteorological information with accuracy 1°×1°) using the website (http://ready.arl.noaa.gov/HYSPLIT.php). The low the meteorological field resolution leads some doubt in the HYSPLIT model. This model includes3 trajectories types that could be computed – normal, matrix, and ensemble. The ensemble path is applied to define multiple routes from one place by all likely aberrations in three coordinates (X, Y and Z) since it decreases the doubt caused by the resolution of meteorology [22]. The backward trajectory of HYSPLIT model computed air masses transport over a through the period 24 hrs at 100 m, 500 m and 1000 m heights AGL(above ground level) to find likely dust activity sources and transport trajectories.

The Aqua and Terra sensors by Moderate Resolution Imaging Spectroradiometer (MODIS) satellite (by NASA agency are widely employed to describe aerosols [23]. For the purpose to support the outcomes of the MODIS satellite images and backward trajectory of the HYSPLIT model, has been employed in the present study. The images of MODIS satellite supplied from NASA agency represents a suitable tool to observe and define dust activity travel employing optical images depend on the radiation and scattering characteristics for particulate matter.

4. Findings and Discussion of the Study

(Figure1) shows the monthly average of aerosol index AI patterns from OMI satellite, temperatures, relative humidity and rainfall during 2004-2020. The observed aerosol index values refer to mineral dust particles in Figure 1a. The high values of the aerosol index are observed from March to September (spring and summer) particularly in June - July, and August in central region (Baghdad city) of Iraq. Whereas low AI values refer to less dust activity over the region from September to February (fall and winter), particularly in December.

In addition, temperatures were increased significantly in summer, particularly in August, while relative humidity was reduced remarkably in summer (Figure 1 b, c). In winter, rainfall and relative humidity were increased in contrast with air temperature distribution. Figure 2 shows dust sources in which the AI values are increased and it has an almost similar shape every month. For instance, eastern parts of Syria, Kuwait, north Saudi Arabia, southwestern parts of Iran, as well as south and central parts of Iraq. Severe and continuous dust events in this region indicates that sites in this region are more likely to be sources of dust activity.

Backward trajectories of HYSPLIT model were employed to identify likely source areas and transport pathways of strong dust storms over Baghdad (31, 31 N and 48, 65 E), the capital city of Iraq, for spring season in 2012. Dust storms trajectories were tracked every six hours interval up to 24- hours prior to dust storms arrived Baghdad at altitudes (100, 500 and 1000 m). In addition, dust aerosols at lower or equal 500 m elevation are large particle and have more weight that can effect visibility considerably. Figure 3 shows four severe dust storms that occurred during spring using different remote sensing techniques (Hysplit model, MODIS, and OMI satellites). The pathway of the dust event on the 17 March 2012 in Baghdad (Figure 3a) revealed that the likely dust source regions of were the drylands along areas between the Iraqi–Syrian borders, Syrian Desert and the Al Jazeera and Western Deserts in Iraq.

The backward trajectory of HYSPLIT for dust storm over the Baghdad city on 17 April 2012 revealed likely source regions of dust activity placed to the northwest on the Iraqi borders (Syrian Desert) and Khuzestan region in the south-western part of Iran and the Al Jazeera and Western Deserts of Iraq (Figure 2b). While, dust storm over Baghdad city on 19 April 2019 originated from local dust sources in Iraq including the Western and Al Jazeera Deserts (Figure 2c). In addition, one dust storm that gotten Iraq on 24 May 2012 impacted Baghdad city.

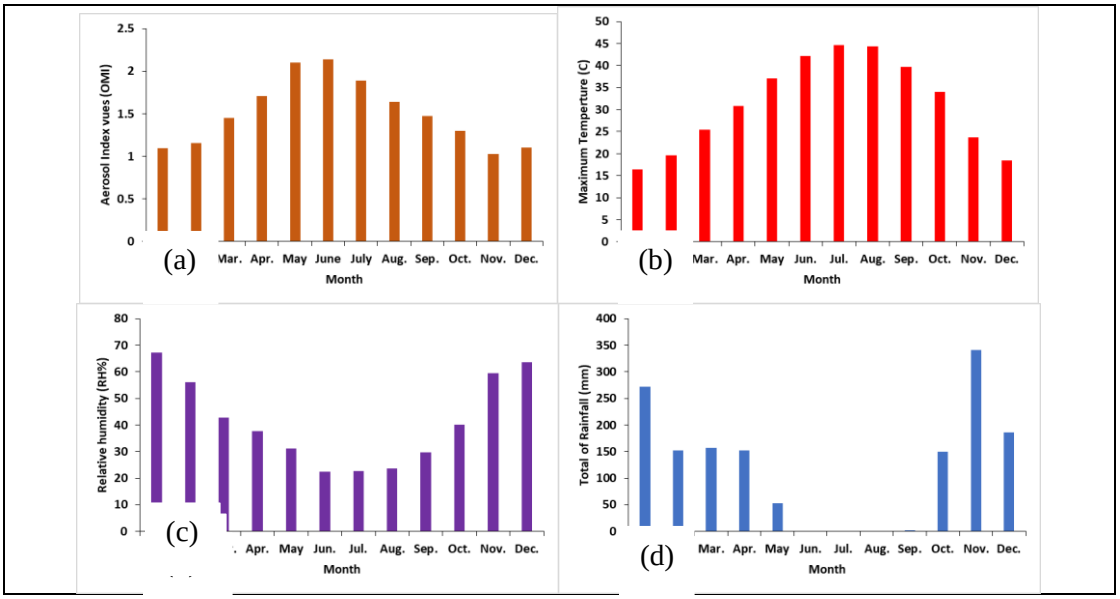

Figure 1. The monthly average of AI patterns by OMI during 2004-2020 (a), Temperature (b) Relative Humidity (c) and Rainfall (d).

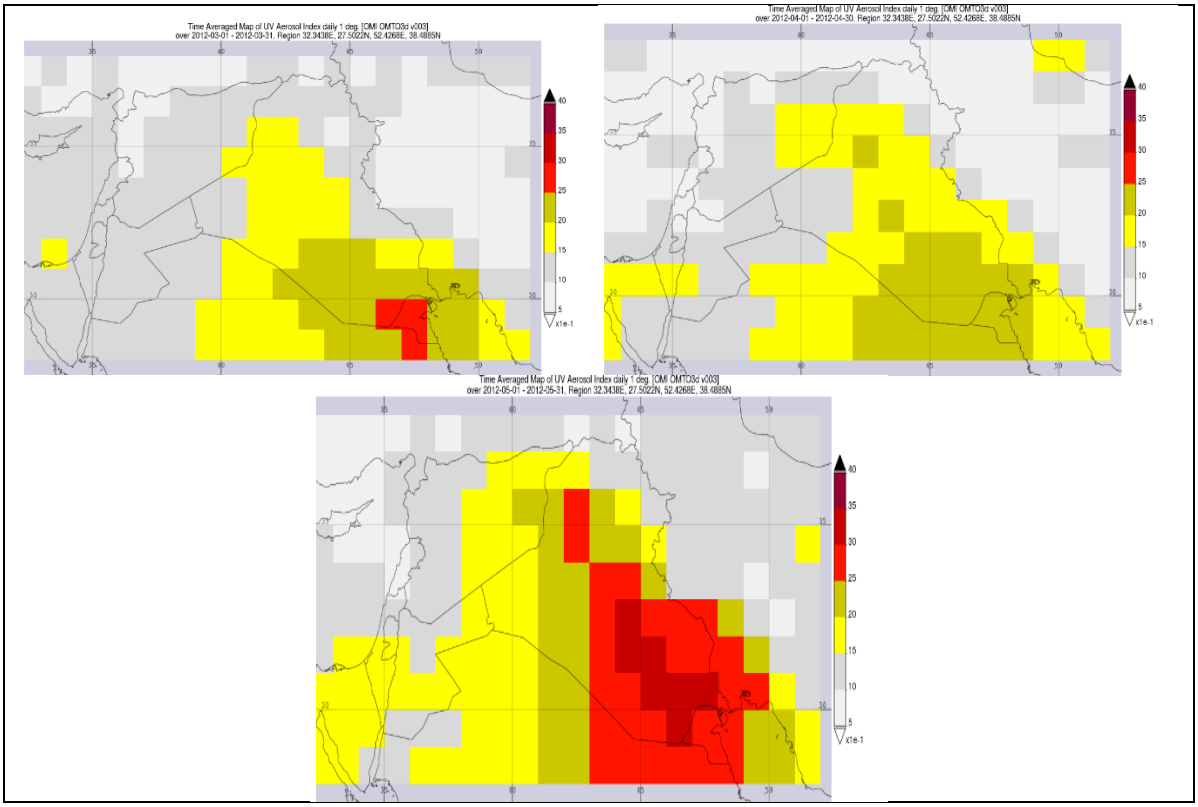

Figure 2. Spatial variation of monthly average AI data for the spring season (March, April and May) over whole Iraq in 2012 the OMI satellite with (1.0˚ x 1.0˚)resolution by: (https://giovanni.gsfc.nasa.gov/giovanni/).

Separate backward trajectory analysis by HYSPLIT model over Baghdad revealed that the possible dust storm sources were the Syrian Desert as well as Western and Al Jazeera Deserts of Iraq (Figure 2d). The backward trajectory consequences of the HYSPLIT model for dust storm transport are agreement with images of MODIS – OMI satellite (dust storms are revealed by the MODIS – OMI satellites).

Based on the analysis of HYSPLIT Model trajectories, the east of Syria and north-west pathways is the major trajectories transported dust storms over Baghdad (figure 3a,b,c,d), that decrease visibility below 1 km in Baghdad (IMO). Another pathway of dust storm originates from western desert towards Bagdad city as shown in Figure 3c. Hysplit results analyses suggest premontane north-west surface wind (Shamal wind), which transport dust grains from eastern parts of Jordan and Syria, and north-west regions of Iraq towards Baghdad city in spring and summer [9]. Syria, southern Turkey and Iraq represents one of the significant source areas of dust events in the Middle East region. There are regional and local causes lead to dust activity occurrence over Iraq. Climate changes at the regional scale represent one of the significant reasons to generate dust storms over Iraq, especially ecological changes such as drying of the marshes, degradation of lands and increase desertification areas as well as low rainfall rates annually. Wars and army operations consider local cause, particularly in the desert region of Iraq [9]. Some studies indicated that the major sources of dust activity which affected Iraq are Syrian Desert, desert areas in the Middle East region (including Turkey, Jordan and Iran, Al Jazeera, Southern and Western Deserts and Alluvial Plain in Iraq, deserts in Saudi Arabia and Sahara [18,24-26]. Dry marshlands (Al-Howizeh lake) between Iraqi and Iran borders and dry areas in west Bagdad represent source areas of dust storms [27].

The degradation of land because of erosion process by impacts of winds most arid areas in the world and leads an increase in dust activity frequency. Incorrect management of soil structure, tillage, and vegetation coverage may cause erosion process by winds through interactions with particular weather conditions. Dust activity can lead to a decrease in agricultural production because of loss to organic matter and damage of nutrient-rich particles caused by soil removal from arid areas [28]. Particulate matter PM (such as atmospheric pollutants e.g. PM10 and PM2.5) can lead to health issues and illness, i.e. breathing issues circulation and plus heart diseases. For instance, a dust event on 09-08-2005 over Baghdad city in Iraq leaded to 1000 suffocation cases and one person to die. Extreme dust events have an influence on airplanes and traffic through decreasing visibility to a short range, particularly close to the dust sources [1].

The CALIPSO trajectory close to Iraq on 17&19 April and 24 May 2012 moves over the east coast part of the Mediterranean Sea region (Figure. 4a, c, e). The 532 nm total attenuated backscatter come back signal in Figure.4a detect the existence of an aerosol layer above the cirrus stratocumulus clouds at elevated elevation (10 - 20) km, but the aerosol layer is distinguished through the CALIPSO trajectory between the Mediterranean Sea and the Middle East region. The aerosol subtype 2 (Yellow) in Figure.4b shows the existence of dust aerosols above west to northwest Iraq (a, in Figure. 4b, d, f).

The National Institute of Aerospace at NASA Langley Research Centre has been employing the information of CALIPSO satellite to define dust plumes height. The information of CALIPSO satellite revealed that the dust storms had extended 18 kilometres. Dust storms are very dangerous that they have transported dust all the way to the stratosphere, something dust storms do only sometimes. (Generally, volcanoes raise dust plumes to such elevations). The radiative heating from the aerosols within the dust creates dust events particularly buoyant, meaning they will arrive high altitudes in the stratosphere and remain there longer than material from a volcanic eruption that transport the same initial altitude.

The surface micro pulse lidar (MPL) ground and CALIPSO information employed to observe transport and vertical distribution of dust particles in Asia region from the Taklamakan and Gobi desert areas. They defined transferred dust particles from the Taklamakan and Gobi desert areas in the west part of Pacific Ocean and east part China by the vertical aerosol structure by CALIPSO data in confirmed by backward HYSPLIT trajectory analyses [29].

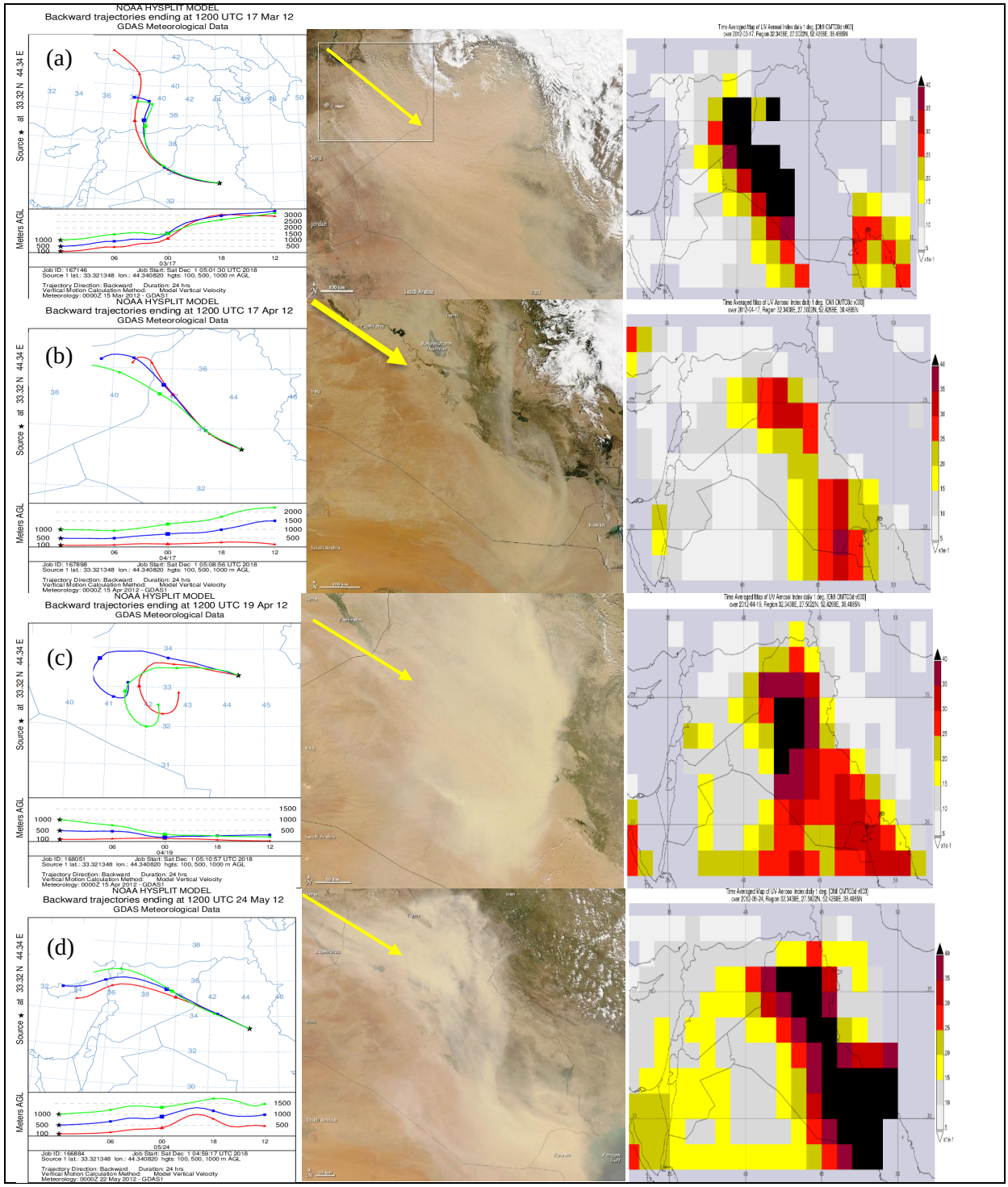

Figure 3. Backward trajectories of HYSPLIT Model and MODIS images with daily average of AI variation for severe dust storms in Baghdad during spring and summer in 2012.

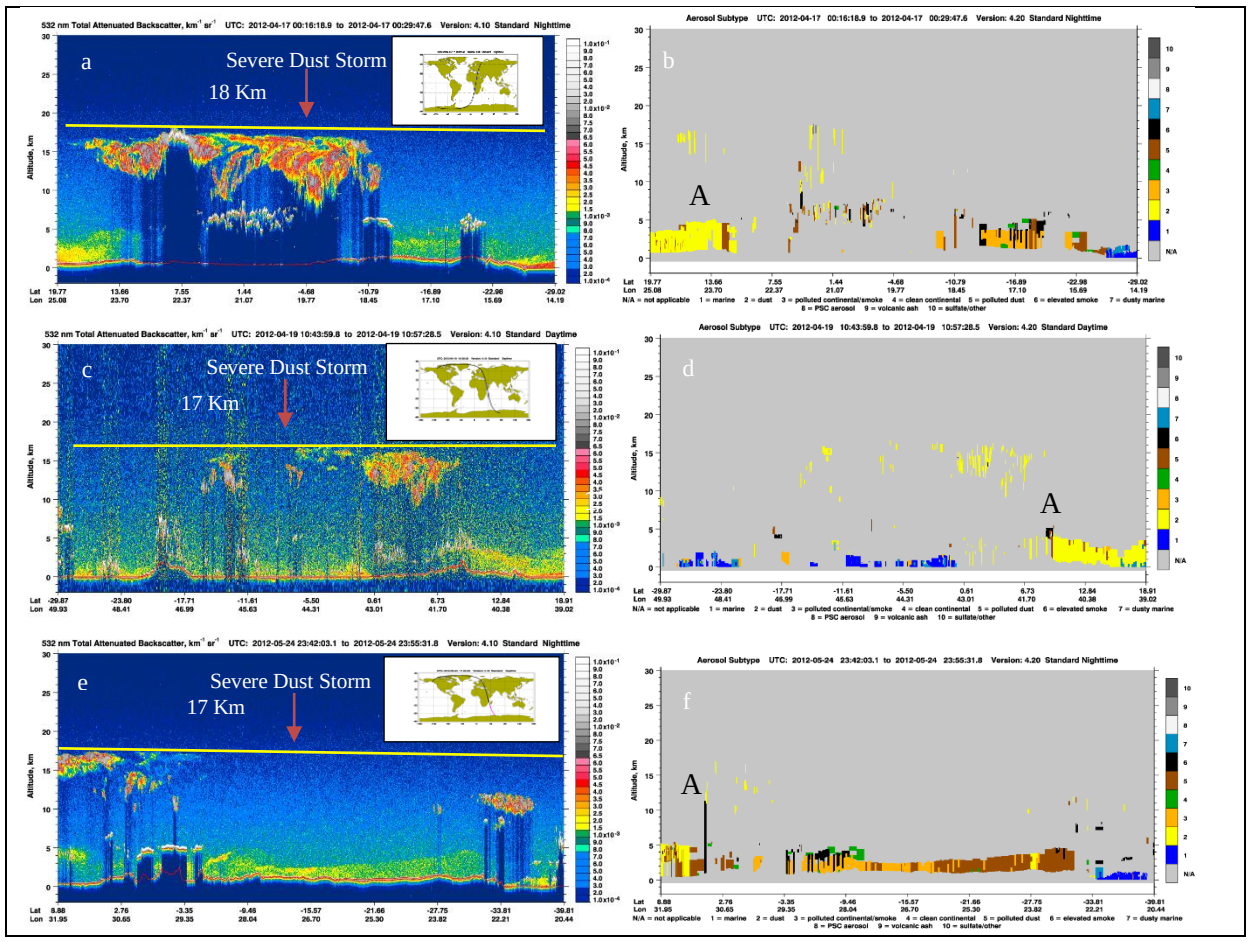

Figure 4. Aerosols measured by CALIOP in the daytime transect (inset) from [− 19.10, 156.43] to [28.88, 145.48] on 17&19 April and 24 May 2012 (a, c, e) 532 nm total attenuated backscatter, (b, d, f) aerosol subtypes 1–6.

Conclusion

The possible sources and transport paths of dust storms over Baghdad city were determined in this present research that examined strong dust storms over Baghdad city during the spring season in 2012. Hysplit results analyses suggest that there are major trajectories to transport dust to central part of Iraq: (i) dust storms are likely transferred from southern Turkey, the east of Syria and north-west parts of Iraq (ii) dust storms are transferred from the western and central parts of Iraq. MODIS and OMI satellites suggest the same sources and pathways of dust storms as the Hysplit model during the dust storms case study.

The aerosol data as recorded via the CALIOP Lidar platform on board the CALIPSO satellite represent so usefully in supplying the sources aerosol fingering and thus the source of causing high particle event near the land in northwest Iraq can be determined.

Dust storms can reduce the visibility which impact the economy through impacting on transportation, agriculture and human health. The frequency of dust storms in Iraq increased climate change and the quantities of available water in the Euphrates and the Tigris Rivers. Any change in the amounts of available water in these two rivers, increase the annual mean of air temperatures and reduction rainfall rates lead to the barren and dry areas. Moreover, increase in dust storms can occur when increasing drought periods which lead to land degeneration and vegetation loss.

Identify dust source areas is vital because of this natural disaster occurrence at a global scale and in order to put the future plans to reduce dust storms impacts in the highly erodible areas. Surface binders of soil, stabilizing soils and Increase vegetation areas can be useful in decrease dust emissions in the

region. Future work should be focus on the efficient methods for vegetation characteristics, weather conditions, and topography and soil type for every dust source area.
The use of meteorological models, including HYSPLIT and CALIPSO and MODIS satellite measurements give the helpful tool for researchers to best understand about dispersion and transport of air pollutants for the long-range and regional scale.

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