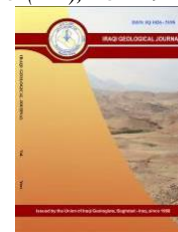




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Dynamical Transportation of Aerosols for Extreme Dust Storms Over Al-Jazira Region

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Abstract

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The characteristics and classifications of aerosol properties over Iraq was studied in this paper. The $1^{\circ} \times 1^{\circ}$ grid of monthly aerosol optical depth and angstrom exponent data of the period 2005 to 2017 in Iraq is used from Terra of MODIS. Moreover, the $1^{\circ} \times 1^{\circ}$ grid of Aerosol Index is used and it is available from NASA's Data and Information Services Center for Earth Sciences (GESDISC). The backtrajectory for 12 dust extreme events over the Al-Jaziraregion was studied by using the Single-Particle Lagrangian Integrated Trajectory model (HySplit-4). The spatial-seasonal aerosol properties over Iraq were obtained from EOS-Aura satellite by Ozone Monitoring Instrument. The high-high clusters of aerosol optical depth and Aerosol Index values which refer to high concentration have been found in western and southern Iraq however low-low clusters have been found in the winter season over the whole of Iraq. According to Angstrom Exponent, there are three kinds of aerosol modes: fine, mixture, and coarse. This classification shows the maximum area under fine aerosols mode has occurred in the winter with 13.6% whereas the spring season did not show any area with fine aerosols mode. Moreover, the coarse mode covers the maximum area during the summer season with 97.7% and the minimum area during the winter season with 77.2%. To demonstrate the relationship between topography and aerosol characteristics, Aerosol Properties Index is used which shows the degree of aerosol coarseness in each pixel. Using Geographically Weighted Regression and Ordinary Least Squares, the Aerosol Properties Index geographical distribution is strongly influenced by topographic conditions. Where the maximum coefficient of determination has been observed in the spring ($R^2=0.91$) from the Geographically Weighted Regression model, while Ordinary Least Squares shows a lower coefficient of determination ($R^2=0.33$), Geographically Weighted Regression in comparison to Ordinary Least Squares shows a better coefficient of determination in all seasons. The back trajectory for extreme dust events shows that some sources of air masses and their path to the study area through two pressure levels (1000 mb, 850 mb) and the geographical desert in the area of the study are the main cause of dust storms in the study area.

Keywords: Iraq; Dust; Aerosol; HySplit-4; Back trajectory; Al-Jazira desert

1. Introduction

Aerosol are recognized as an essential component of Earth's atmosphere due to their impacts on climate, economic and health. The cumulative impact of aerosols on climate is typically evaluated in terms of radiative forcing (Tariq and Ul-Haq, 2018). A new report from the World Health Organization (Organization, 2021), revealed that aerosols is among the most dangerous to human health, (Du et al., 2016, Gharibvand et al., 2017; Al-Salihi, 2018).

Currently, several countries across the world govern and continuously track PM atmospheric levels (Alqurnawy et al., 2022). Common daily and/or annual limits are usually set for PM_{2.5} and PM₁₀. Aerosols have a major and clear effect on climate change. The main influence of aerosols on climate patterns was inconsistencies in radiation budgets for direct or indirect impact (Yousefi et al., 2020; Ji et al., 2011; Yang et al., 2018). Aerosols also have a significant source of instability in the climate system within identified atmospheric substances, which vary both spatially and temporally. Owing to our limited knowledge of the Spatial and temporal distribution and aerosols properties, there is significant variability in the quantification of aerosol radiative force. (Tariq and Ul-Haq, 2018). Aerosol particles have a direct impact on the Earth's energy system by their interactions with solar and terrestrial radiation. The direct radiative effect of aerosol (RE_{ari}) is characterized as a variation in radiative fluxes induced by aerosol partials. Aerosol also impacts the Earth's radiation budget indirectly through its involvement in cloud production and by modulating the radiative effects of clouds through a variety of different mechanisms (e.g., cloud albedo modification or cloud lifetime) (Witthuhn et al., 2020).

Aerosol optical depth (AOD) is the most detailed indicator used for remote measurement of the load of aerosols in the atmosphere and used to represent the loading of aerosol columns. In recent years, remote satellite sensors and ground-based data have been commonly used to study the spatiotemporal distribution of aerosols on a different scale. Satellite instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging Spectroradiometer (MISR), Total Ozone Mapping Spectrometer (TOMS), and Ozone Monitoring Instrument (OMI), are used to detect aerosols at regional and global scales to have long-term to continuous monitoring for the region of study (Filonchik et al., 2019). Evaluation and inter-comparison of AOD satellite products is difficult for a number of different reasons: data persists in various formats, over different time periods that can converge only slightly, computational requirements (especially for L2 data) are high, and data typically comes in different spatio-temporal grids. Recently, a lot of data from satellite were used to classify the global accumulation of aerosols has commonly used data from MODIS. Many studies have proposed different aerosol detection algorithms using MODIS (Zhang and Reid, 2010). Extensive efforts have been made to track aerosols with (AOD), Ångström exponent (AE) and Absorption Aerosol Index (AAI) as the main optical aerosol characteristics that are regularly tested. Useing of ground-based aerosol networks (e.g., Aerosol Robotics Network (AERONET) (Holben et al., 1998) (Hu et al., 2018). Nevertheless, they require expensive and complex equipment and occupy fairly limited areas (Kang et al., 2016; Adesina et al., 2017). Past and new research have demonstrated that doubts existing in products of satellite for aerosol due to instrument configuration, complicated surface area, cloud aggregation (Levy et al., 2015; Mehta et al., 2016; Boiyo et al., 2017, De Leeuw et al., 2018). Owing to significant uncertainties in the spatiotemporal distribution of aerosols across the globe, the regional and global effect of atmospheric aerosols on the atmosphere remains unclear. This variation is due to the high variety of the sources of origin of the various aerosols as well as their limited period of residence in the atmosphere (Rezaei et al., 2018; Srivastava et al., 2016). Previous studies Investigated the spatial-temporal variability of aerosols in different regions of the world, referring to stable atmospheric conditions, high temperature, high humidity and low elevation, which result in a high concentration of AOD in the region (Zayakhanov et al., 2012; Cheng et al., 2015) (He et al., 2016; Boiyo et al., 2017). In Iraq, there is no site of Aerosol Robotic Network (AERONET), All related research works depend on

satellite data satellite data which provide a good opportunity to monitor spatio-seasonal heterogeneity of aerosol properties. A limited number of studies have been submitted in Iraq to study the characteristics of atmospheric aerosols and its impact on some climatic and environmental parameters (Awadh, and Ahmad, 2012; AL-Salihi, 2017; Awadh., 2012). This study has aimed on two main objectives: First, investigation and study the spatial and seasonal distributions of physical and optical properties (AOD, AI and AE) over Iraq, the second aim represents by determination the origin and source of the extreme air masses, a Lagrangian technique was used, which involved computing backward trajectories using (HySplit-4) over al-Jazira Region.

2. Materials and Methods

2.1. Satellites Types

There are two satellites (Terra and Aqua) consisting of the Resolution Imaging Spectroradiometer instrument MODIS which are part of NASA's Earth Observing System (EOS). The mission of MODIS giving spatial and temporal information about aerosols. These satellites have measurement data by 36 channels of the wavelength range from 0.4 to 14.4 μm with various resolutions and their altitude at 705 km. At 10:30 LST Terra crosses the equator whereas Aqua crosses the equator at 13:30 LST. More details could be found in (<http://modis.gsfc.nasa.gov>). The $1^\circ \times 1^\circ$ grid of monthly AOD and angstrom exponent (AE) data of the period 2005 to 2017 in Iraq is used from Terra of MODIS. Moreover, the $1^\circ \times 1^\circ$ grid of Aerosol Index (AI) is used and it is available (GESDISC). The spatial-seasonal aerosol properties over Iraq were obtained from the EOS-Aura satellite by Ozone Monitoring Instrument (OMI).

The technique Anselin Local Morans is applied in this paper to identify outliers feature cluster and outlier analysis in addition to the determination of locations that could be found with high and low AOD and AI values in terms of significant clustering. The study area is noticed as three parts according to the aerosol model of AE values (fine, mixed and coarse) as shown in Table 1. The aerosols properties Index (API) are figured out based on a combination between the concentration and size of aerosol. The AOD and AI values refer to the concentration of aerosol whereas the AE their size. Thus, when apply this fact in some regions we can express for this relation between API and aerosols parameters as, high API coarse mode and the low API fine aerosol mode, in a region which we can write it as equation 1. Because of the region topography has an effect on aerosol properties index API, the comparison between GWR and OLS models could be convenient for understanding the relation between aerosol characteristics and topography. At each grid point, dust extremes events were defined as those events in which API was above its 99.9th percentile for the twelve years. The highest 12 values of (API) were recorded in years 2016 and 2017 over al-Jazira region.

2.2. HySplit-4 Model and the Back Trajectory

In order to determine the origin and course of the extreme air masses, a Lagrangian technique was used, which involved computing backward trajectories. NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory model (HySplit-4) [<http://www.arl.noaa.gov/ready/hysplit4.html>] was used to construct 4-day back-trajectories using gridded NCEP/NCAR reanalysis data. Trajectories were calculated at 500 m a.s.l. at the moment of the episode's beginning for 12 dust extreme events over al-Jazira region.

3. Results and Discussion

The spatial and seasonal distributions of physical and optical properties (AOD, AI and AE) over Iraq were represented in Figs. 1, 2 and 3 respectively. Where the AOD mean values of Winter, Spring, Summer and Autumn are 0.207 ± 0.066 , 0.430 ± 0.131 , 0.401 ± 0.121 and 0.293 ± 0.088 respectively. The maximum value was in Summer (JJA) about 0.850 in middle of IRAQ, whereas the minimum value was 0.101 in Winter (DJF) in North of IRAQ. In Spring (MAM) season was noticed the AOD Values takes range between 0.288-0.664 likewise, the Autumn (SON) season where the AOD value takes range between 0.101-0.570 as shown in Fig 1. In addition, the AI mean values of Winter, Spring, Summer and Autumn are 1.074 ± 0.010 , 1.386 ± 0.032 , 1.447 ± 0.036 and 1.141 ± 0.019 respectively. The AI maximum value is 2.600 in JJA in south of IRAQ and minimum value is 0.741 in SON in north of IRAQ. However, in the DJF the AI values are between 0.860-1.583 over IRAQ as illustrated Fig 2.

On the other hand, in Fig 3, it was noticed that the AE mean values of Winter, Spring, Summer and Autumn are 0.847 ± 0.033 , 0.610 ± 0.038 , 0.548 ± 0.032 and 0.747 ± 0.031 respectively. The AE maximum value is 1.629 in JJA in north of IRAQ whereas the AE minimum value is 0.054 in JJA in desert regions also. The AE have same behavior in DJF, MAM and SON seasons. Figs. 4, 5 represents the spatial maps of AOD and AI, which clustered of all seasons respectively. The employed approach has a powerful capability of High and low classifications' AOD and AI data in Iraq. As shown in Fig. 4, winter season characterized by a lowest high, cluster of AOD concentrated in Al Muthanna and Basra governorate, whereas Spring and Summer seasons presented the highest high cluster of AOD over southern and al-Jazira region along the Iraq-Syrian border. And finally, during Autumn season, the high cluster AE is a qualitative indicator, which provides information for each fine-and coarse-mode aerosol. As mentioned in the above methodology section, regions with different aerosol modes are determined based on AE values, thus dividing Iraq into three distinct regions, i.e. fine mixed and coarse aerosol mode, as shown in Fig. 6. AOD can be observed in separated regions over Iraq such as al-Jazira, middle Euphrates and Samawah desert respectively, in contrast the low cluster of AOD appeared over Zagros mountains. Fig 5 illustrated the spatial distributions of AI during the four seasons from winter to Autumn where the highest high cluster observed over southern region especially in Samawah desert and Basra city in all year seasons however the al-Jazira region shows the high cluster during the season' Winter, Summer and Autumn.

In Fig. 7, scatter plot represents the relation between predicted API values and the estimated one, using GWR and OLS. As can be seen, GWR, in comparison to OLS, shows a better coefficient of determination in some seasons. The maximum coefficient of determination has been observed in the spring ($R^2=0.91$) from GWR model, while OLS shows lower coefficient of determination ($R^2=0.33$), indicating that the API geographical distribution is strongly influenced by topographic conditions.

As seen in Fig. 8, the illustrated maps of local R^2 value show the model's performance in each pixel during all seasons. The overall local R^2 for Iraq during winter, spring, summer, and Autumn are 0.40, 0.44, 0.42, and 0.42, respectively. In all seasons, the maximum performance of the model (High R^2 values) has been observed in the western region, suggesting that in these regions, height and API values are low and high, respectively. For example, in the spring maximum local R^2 has been seen in the western region (latitude= 35.5, longitude= 42.5, height= 201 m, API= 1.27) with an amount of 0.66, whereas the minimum values have been observed in the central region of Iraq and Samawah desert. This is probably due to the transfer of aerosols from distant areas. For example, in the spring, minimum local R^2 (0.017) has been seen in Samawah desert region (the Iraq border with Saudi Arabia) (latitude=44.5 longitude=29.5, height = 387-meter, API= 2.32).

There has been little literature about the relation between topography and aerosol properties; however, our results are consistent with the previous studies that showed the association of topographical structure and spatial distribution of aerosol properties (Collaud Coen et al., 2018)

mentioned that in non-forested regions, dust storm frequency increased as the fraction of closed topographic depression rose, likely due to the accumulation of fine sediments in these areas. (Jiang et al., 2019) reported that two low AOD centers were located in China: the high-latitude region in Northeast China with AOD of about 0.2 and the high-altitude region in Southwest China with AOD from 0.1 to 0.2. They stated that the Tibetan Plateau in the west may be regarded as an essential big topography in the dispersion of aerosols across China.

3.1. The Back Trajectory Analysis

The back trajectory for extreme dust events in the al-Jazira area for the years 2015,2016 and 2017 at level 500 m are shown in Fig. 10-blue line. The air that affects the study area is shown a different behavior which led to generating the dust storm, in addition, there are three types of air source causes a dust storm in the study area. The first region is coming to an area from the African Sarah region and Sudan (c, g, k) which led to an increase in the rate of aerosols in the air mass that coming to the study area. In contrast, there were three cases (I, j, L, b) whose sources from the Arabian desert led to making the air masses loaded with a large number of aerosols and dust upon its arrival to the study area. Finally, there have been instances where air masses have originated in the Mediterranean basin countries of Turkey and Romania. In summary, more than 75% of dust storms are caused by air masses from outside the study area; the desert geographical area surrounding the study area is the main reason for the formation of dust storms, especially if they coincide with the expansion of the air depression from the Red Sea. These results are consistent with previous studies that stated that the desert ocean of the study area from neighboring countries is the main cause of dust storms.

The back trajectory for extreme dust events over al-Jazira area for the years 2015,2016 and 2017 at level 3000 m are shown in Fig. 9-red line. The air mass that affects in the study area shows a different behavior compared with results at 500 m level, where the African Sahara and Syrian desert air masses are shown in seven cases (b, c, g, h, j, k, l) which represent 60% of a dust storm in the study area. In addition, the air mass is cared many aerosols regard to geographical nature of air mass region and air masses at the 500m and coming from the African Sahara and Sudan correspond to the air masses at an altitude of 3000m. This leads to a deepening of the air masses laden with aerosols and dust.

Table. 1. The aerosol mode of AE values

Fine	AE > 0.95
Mixed	0.85 < AE < 0.95
Coarse	AE <0.85

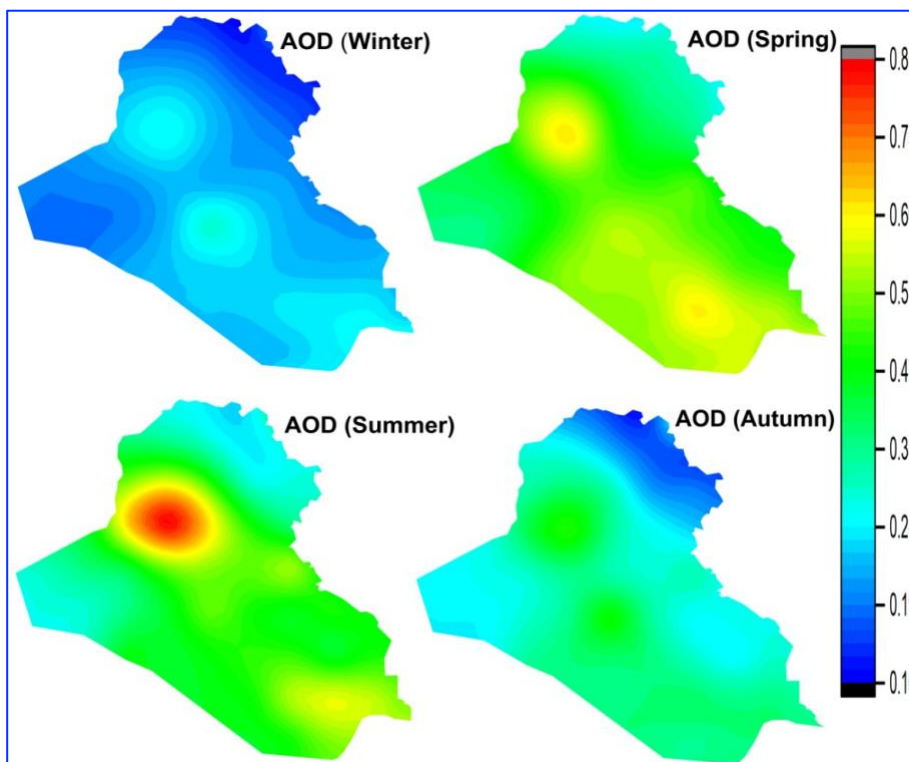


Fig.1. Spatio-Seasonal variation of AOD for period 2005 and 2017 over Iraq

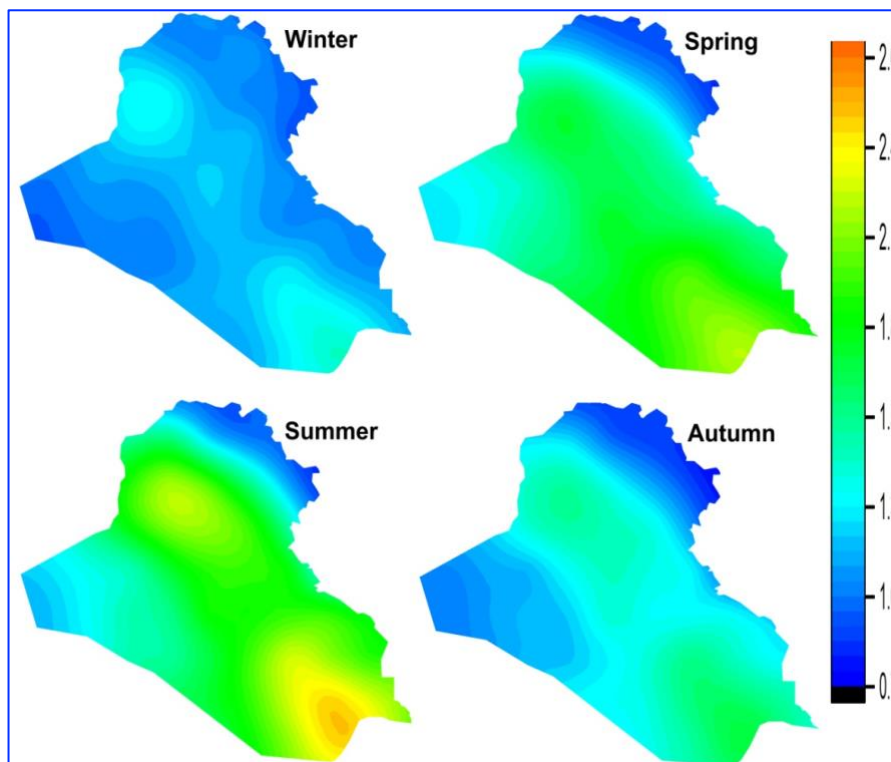


Fig.2. Spatio-Seasonal variation of AI for period 2005 and 2017 over Iraq

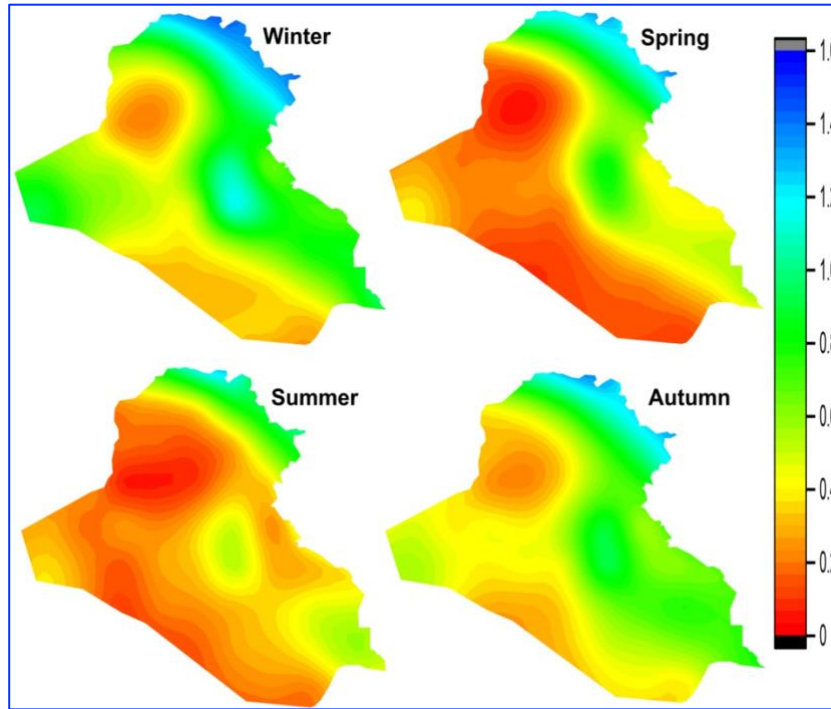


Fig.3. Spatio-Seasonal variation of AE for period 2005 and 2017 over Iraq

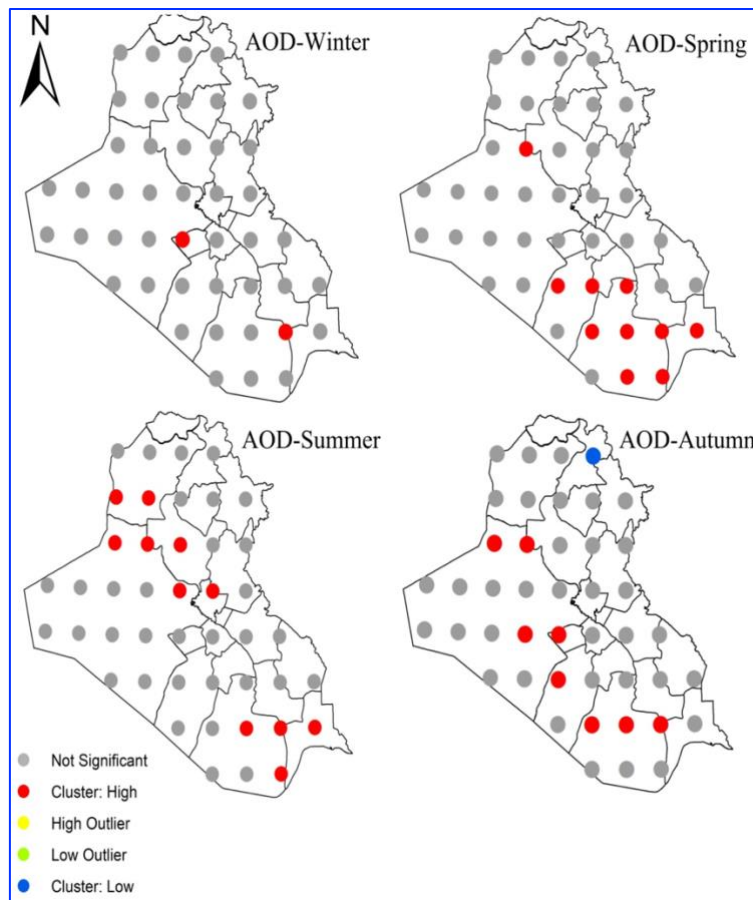


Fig. 4. Seasonal long-term AOD clusters and outliers for the period 2005 and 2017

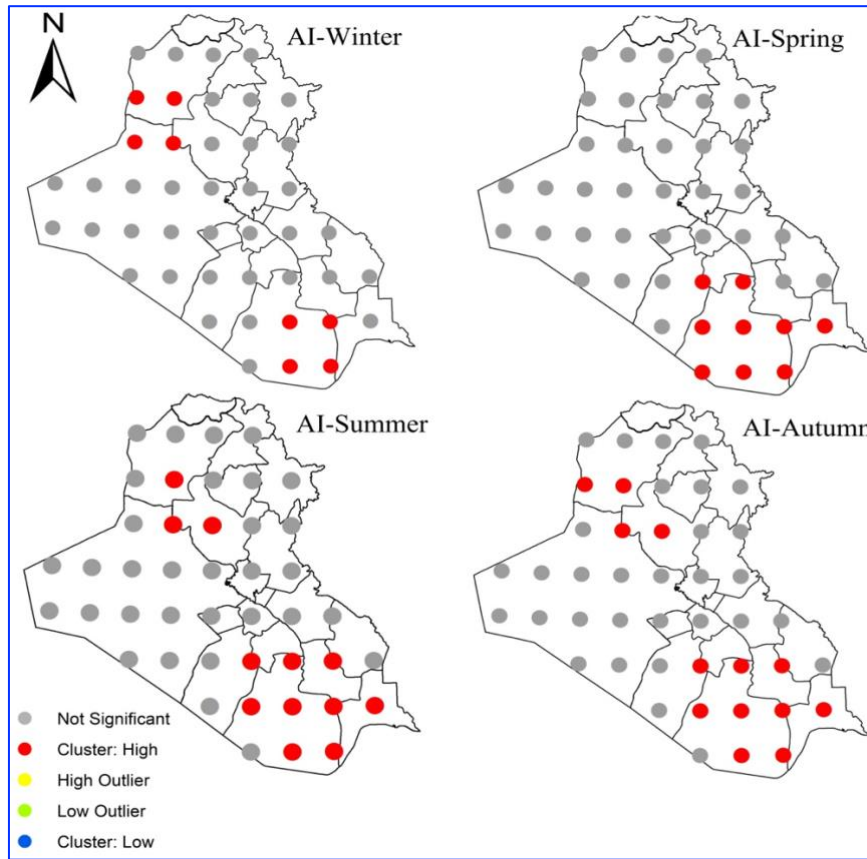


Fig. 5. Seasonal long-term AI clusters and outliers for the period 2005 and 2017

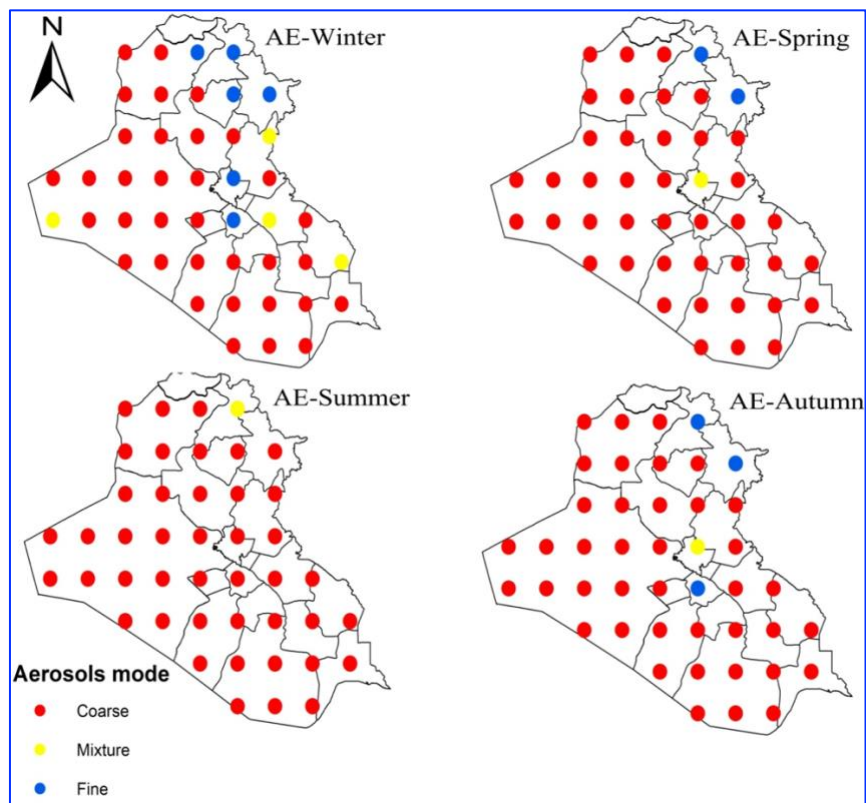


Fig. 6. Seasonal long-term AE clusters and outliers for the period 2005 and 2017

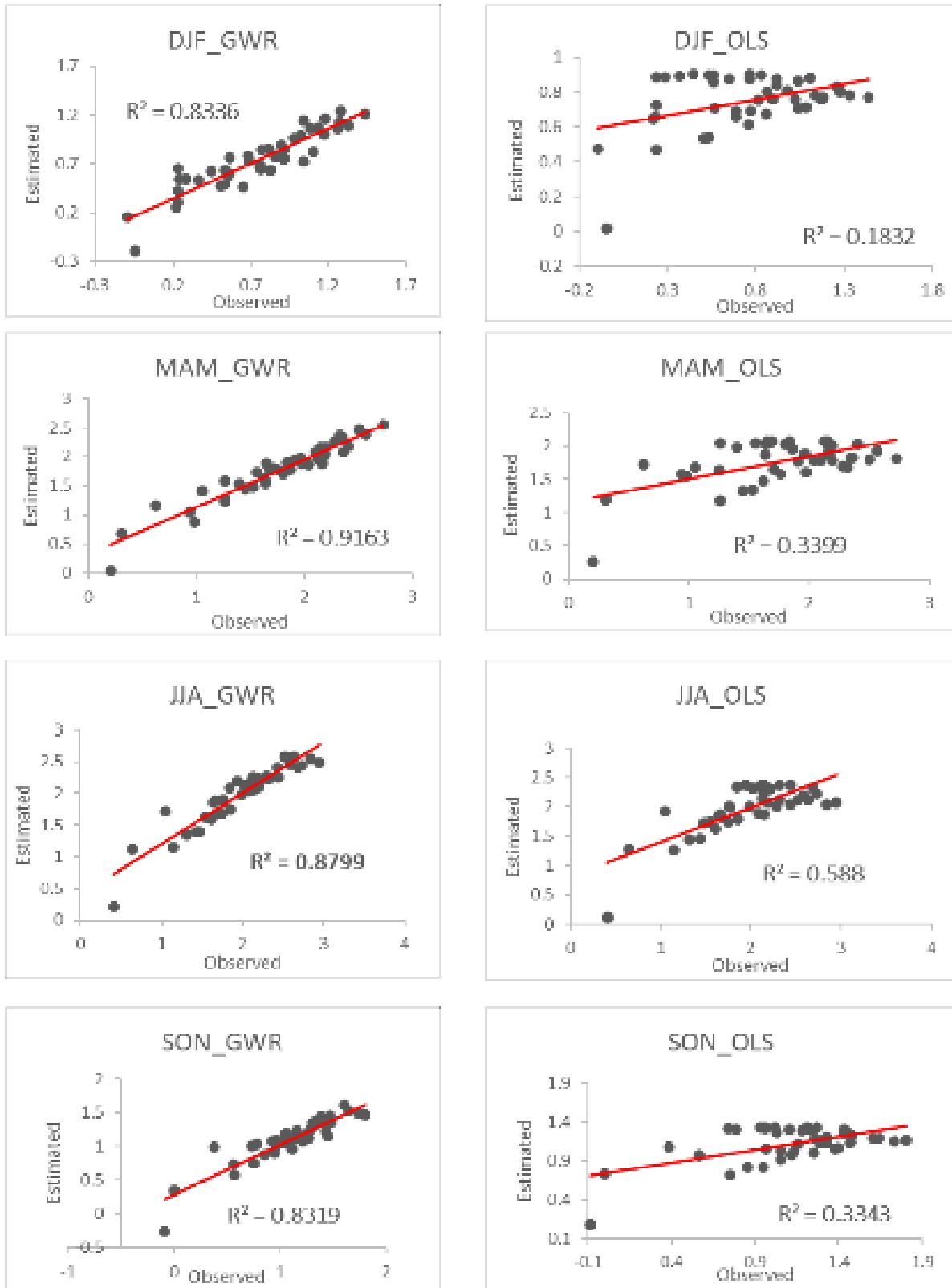


Fig. 7. Scatter plot of observed and estimated values of API by GWR (left side) and OLS (right side) models

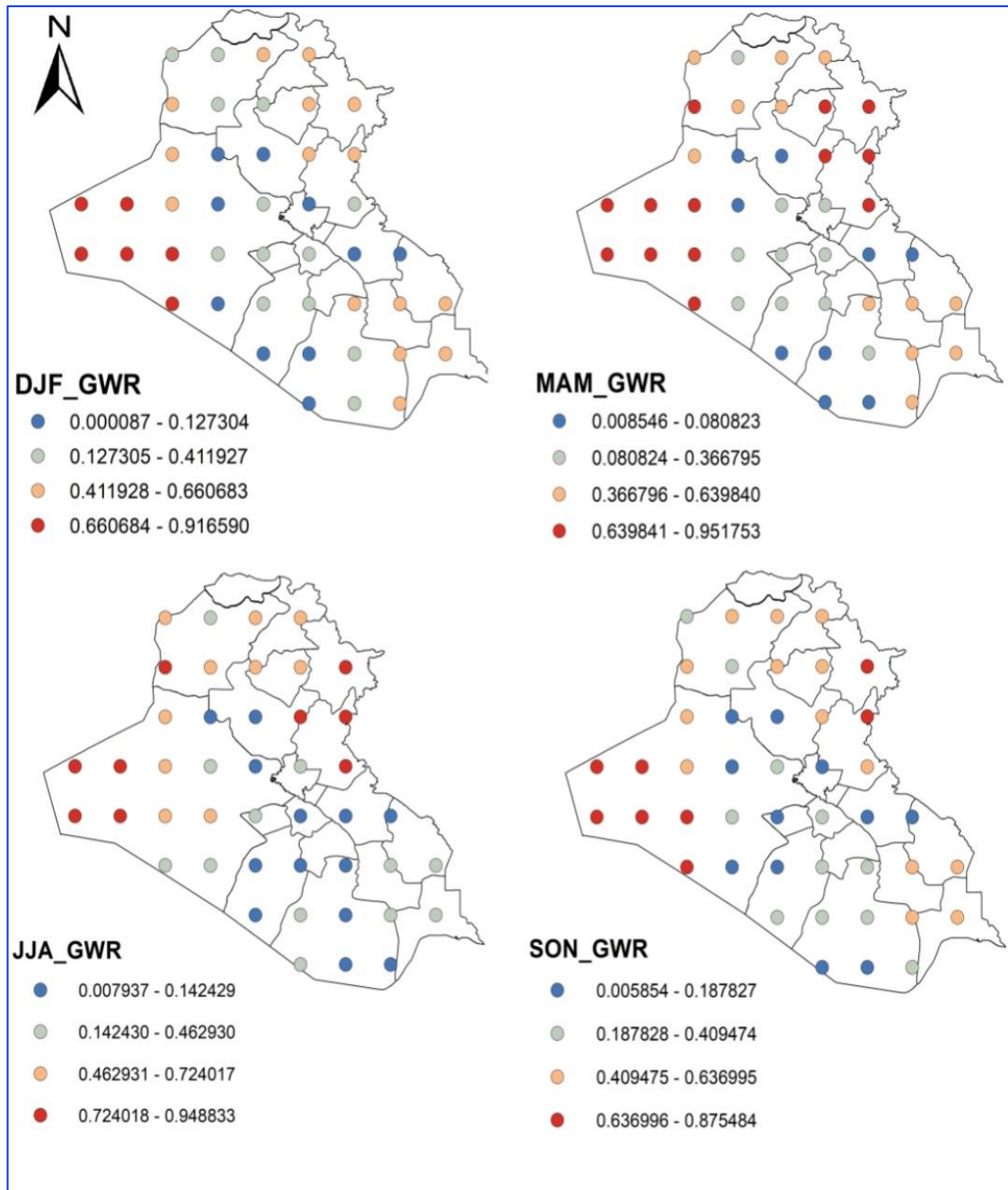


Fig. 8. Geographical distribution of local R^2 in Iraq during different seasons

3.2. Formatting of Mathematical Components

By using the equation

$$API = AOD + AI - AE \quad (1)$$

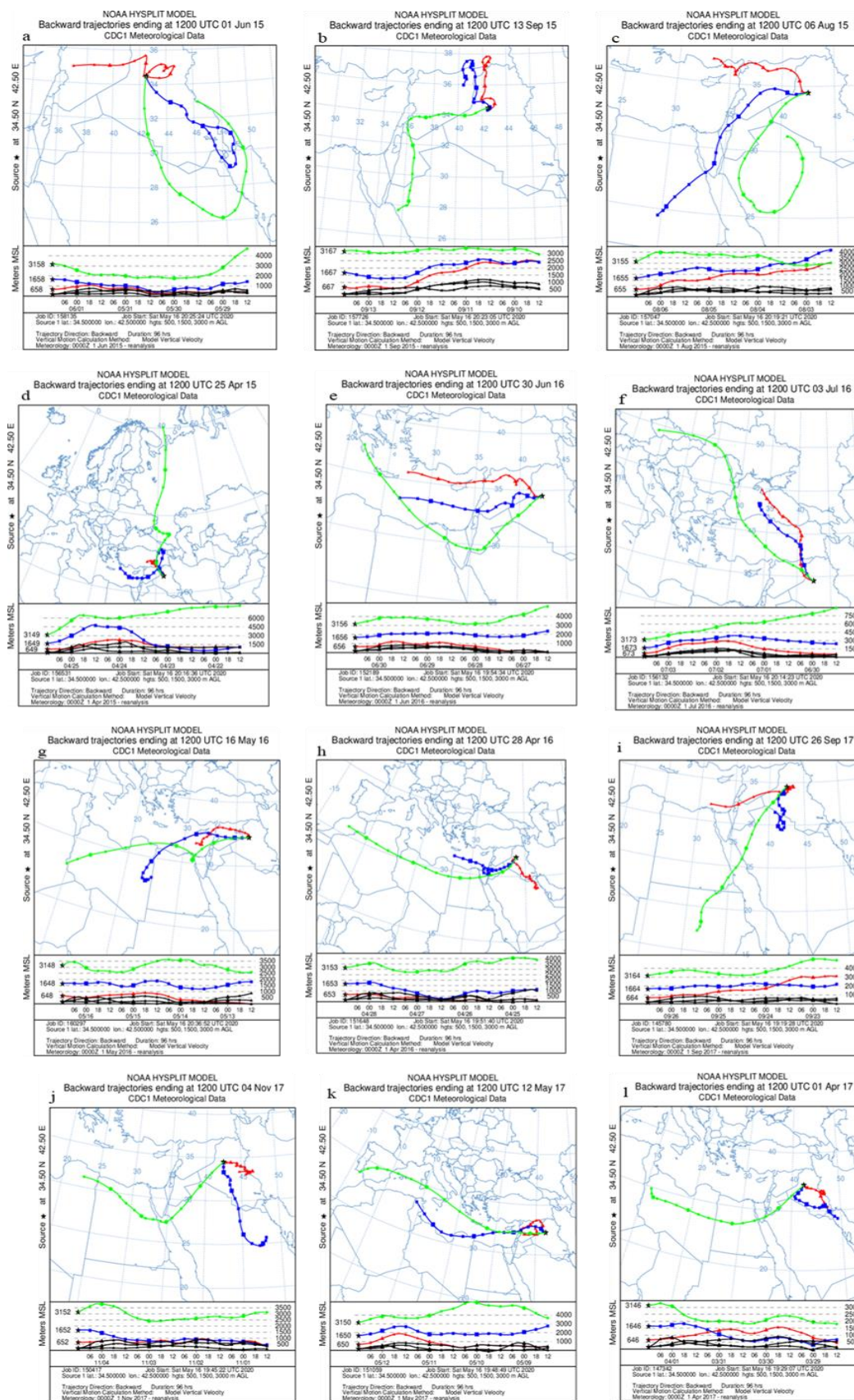


Fig.9. The back trajectory for 12 dust extreme events over the Al- Jazira region, the red line represents the pathway for air mass before 4 days above 500m, the red line over 1500m and the green line over 3000m.

4. Conclusions

The high-high clusters of AOD and AI values which refer to high concentration have been found in western and southern Iraq however low-low clusters have been found in the winter season over the whole of Iraq. According to AE, there are three kinds of aerosol modes: fine, mixture, and coarse. This classification shows the maximum area under fine aerosols mode has occurred in the winter with 13.6% whereas the spring season did not show any area with fine aerosols mode. Moreover, the coarse mode covers the maximum area during the summer season with 97.7% and the minimum area during the winter season with 77.2%. To show the relation between aerosol properties and topography, Aerosol Properties Index (API) is used which shows the degree of aerosol coarseness in each pixel. Using Geographically Weighted Regression GWR and Ordinary Least Squares OLS, the API geographical distribution is strongly influenced by topographic conditions. Where the maximum coefficient of determination has been observed in the spring ($R^2=0.91$) from the GWR model, while OLS shows a lower coefficient of determination ($R^2=0.33$), GWR in comparison to OLS shows a better coefficient of determination in all seasons. The back trajectory for dust extreme events shows that some sources of air masses and their movement to the study area through two pressure levels (1000 mb, 850 mb) and the geographical desert in the study area are the main cause of dust storms in the study area.

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