INVESTIGATIONS ON THE SEASONAL AND INTER-ANNUAL VARIATIONS OF THE ATMOSPHERIC AEROSOL OPTICAL DEPTH IN THE UNITED ARAB EMIRATES USING MODIS SATELLITE DATA

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ABSTRACT

Air pollution has a significant impact on human health. Aerosols or particulate matter (PM) with aerodynamic diameter less than 2.5 μm (PM2.5) is especially of major concern to human health because they can be inhaled easily into the lungs and cause serious respiratory health problems. It has been observed in the UAE that short-term exposures to common air contaminants such as fine particulate matter are linked with increased hospital admissions due to cardio-respiratory conditions, increased emergency room visits and work/school absenteeism, increased respiratory symptoms and decreased lung function. Long-term exposure is associated with increased deaths due to cardio-respiratory conditions, permanently damaged lung function, increased number of people with lung cancer, and increased premature births and low birth weight. The formation of such pollutants depends upon the sources of their precursors (natural or anthropogenic). The challenges of meeting air quality standards are impacted by identifying theses sources and further the trans-borders transport of the pollutants.

Air quality monitoring has been always achieved with networks of ground monitoring stations and the use of models that evaluate emissions and predict changes in air quality. However, these ground monitors often miss pollution that is not within the sampling area of the measurement and are unable of capturing pollution for a large area. Satellite remote sensing is a viable method for monitoring air pollution over a large spatial extent on continuous basis. Advancement in satellite remote-sensing techniques has opened new corridors for the monitoring and mapping of air pollution over large regions. Currently, there are several satellites in orbit that have instruments suited for air quality measurements.

This research project uses the Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric aerosol optical depth (AOD) product, as an indicator of air pollution, for investigating its seasonal and inter-annual variability over the United Arab Emirates (UAE). The research helps to highlight the formation of air pollutants (particulate matter) natural or anthropogenic in the UAE, their seasonal and inter-annual variability and spatial distribution. In this regard, the AOD images over the UAE were analysed from 2006-2015 along with corresponding meteorological observations of air temperature, wind speed, air pressure for the same period. The preliminary findings indicate significant rise of AOD during the summer period due to increased wind speed and high temperatures. The spatial distribution of AOD over the UAE shows that AOD is not particularly higher in desert areas as previously thought, but along coastal regions due to increased humidity and water vapour content during the summer months. Furthermore, AOD in the UAE is primarily influenced by climatic conditions than industrial anthropogenic effects particularly from the hydrocarbon industries.

INTRODUCTION

Air pollution is among the rising health hazards in the UAE in the past decade. It has been observed in the UAE that short-term exposures to common air contaminants such as fine particulate matter are linked with increased hospital admissions due to cardio-respiratory conditions, increased emergency room visits and work/school absenteeism, increased respiratory symptoms and decreased lung function. The sources of air pollutants can be both natural and anthropogenic in the UAE, furthermore, transboundary transport pollutants add an additional source.

Air pollution has been always achieved with networks of ground monitoring stations and the use of models that evaluate emissions and predict changes in air quality (Holben et. al., 2001). The ground monitors have obvious advantages. The measurement techniques can be standardized and applied across all locations. They can measure pollution 24 hr/day and provide hourly, daily, monthly, or any type of time average. They can measure pollution regardless of clouds because these are filter-based measurements that are usually fixed at the surface. However, they also have certain disadvantages. The obvious one is that they are point measurements and are not representative of pollution over large spatial areas and therefore cannot capture the gradients in pollution. These ground monitors often miss pollution that is not within the sampling area of the measurement and are unable of capturing pollution for a large area. Moreover these ground monitors are expensive and require regular maintenance. Also, the lack of a large scale picture makes it difficult to assess where the pollution is coming from and where it is heading.

Satellite remote sensing is the only viable method for monitoring air pollution over a large spatial extent on continuous basis. Advancement in satellite remote-sensing techniques has opened new corridors for the monitoring and mapping of air pollution over large regions. Currently, there are several satellites in orbit that have instruments suited for air quality measurements. Polar orbiting satellites make reliable and repeated measurements over the globe with high spatial resolution when compared with surface instruments, which are limited because they are point observations. The processing of satellite-calibrated spectral radiance data provides estimates of the columnar contents of various atmospheric constituents on regular and continuous basis. However, in order to derive satellite-based concentrations of pollutants (PM2.5) at ground level, it is necessary to integrate satellite data with ground-based measurements (e.g., meteorology, height information from space/ground-based lidars) and/or modelling simulations) (Gruguric, et. al., 2014).

The primary objectives of this research study are to investigate the relation between the seasonal and inter-annual variations of aerosol optical depth, as an indicator of air pollution, over the UAE using remotely sensed data and meteorological ground observations. The underlying hypothesis is that the inter-seasonal variability of AOD in the UAE is influenced by changes in climatic and seasonal conditions rather than due to industrial anthropogenic pollutants. The research study uses the Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric aerosol optical depth (AOD) product, as an indicator of air pollution, for the study period 2006-2015.

STUDY AREA

The UAE is located on the south-eastern limit of the Arabian Peninsula between latitudes 22˚ 50′- 26˚ 4′ north and longitudes 51˚ 5′ - 56˚ 25′ to the east in the largest arid region of the world. It covers an area of approximately 83,600 km2 with major geomorphological features. The UAE landscape is diverse and includes high mountain regions particularly along the border of Oman, coastal sandy beaches along the Arabian Gulf and the sea of Oman, and vast inland deserts. The UAE deserts cover a significant portion of the total UAE area and are predominantly occupied with different types and shapes of sand dunes. These dunes range from smaller sized sand pockets to mega large dunes particularly in the southern part of the country making them a dominant landscape feature in the UAE. The dominance of the desert landscape in the UAE make it much more prone to increased AOD due to sand movement and sand storms. The climate of the UAE is extremely arid with sporadic low precipitation rainfall in the winters.

DATA

Satellite Data

Several satellites data are currently available that provides extensive coverage spectrally and temporally over the study area. This research uses data that comes from the Moderate Resolution Imaging Spectroradiometer (MODIS) (http://modis.gsfc.nasa.gov/about/) for mapping the AOD over the study area (Remer et. al., 2005). MODIS is one of the key sensor instrument aboard the Terra and Aqua satellites collection data over the entire globe every 1-2 days (Letelier and Abbott 1996). MODIS collects spectral data over the entire globe in 36 spectral bands in the visible, near-infra-red and short wave infra-red parts of the electromagnetic spectrum. Furthermore, MODIS collects data also in the thermal portion of the spectrum. The choice of the spectral ranges of MODIS spectral data was based on the different data applications intended.

An AOD product is derived on continuous basis from MODIS spectral reflectance measurements over land and oceans (Levy et. al, 2007; Levy et. al., 2015). This research study uses the monthly mean derived aerosol optical depth product from the MODIS/Terra for the period 2006-2015. The period was chosen to coincide with the available ground meteorological observations.

Meteorological Observations

Data from the National Center of Meteorology & Seismology (NCMS) in Abu Dhabi were acquired for six climate stations. The data represented the mean monthly observations for temperature, wind speed and air pressure. The climate stations were chosen to cover the entire UAE to insure accurate interpolation for the above meteorological observations.

METHODOLOGY

Data Interpolation
The meteorological data represented the mean monthly values of temperature, wind speed, and air pressure for the period 2006-2015. An interpolation process was carried out to generate wind speed, temperature and air pressure layers for the study area using the data from the climate weather stations. The inverse distance weighting (IDW) interpolation was applied for the meteorological data set. Interpolation process helps to predicting the value of attribute at un-sampled sites from measurements made at point locations within the same area or region. Figure 1 shows the interpolation results for the temperature for 2014 (others are excluded for brevity).

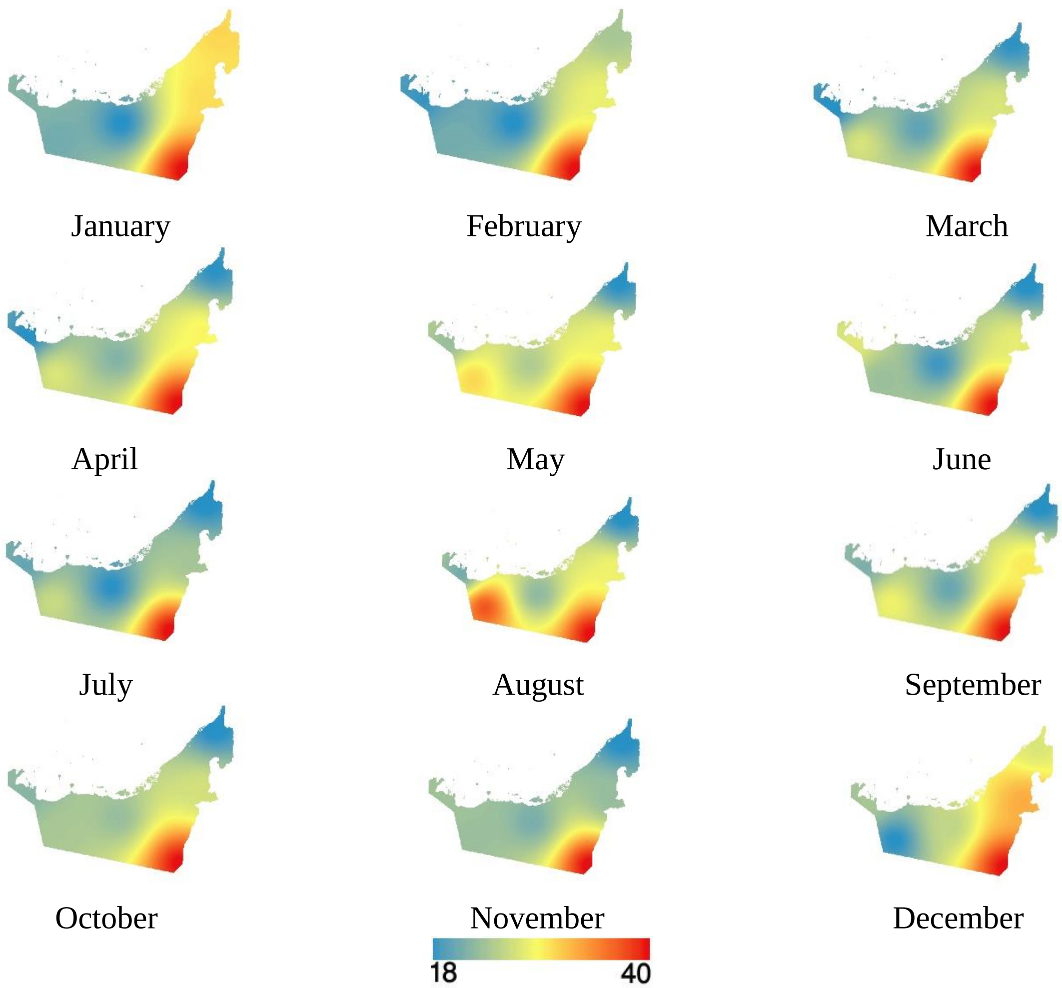
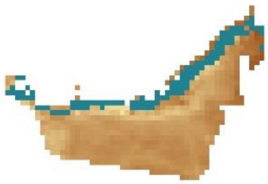
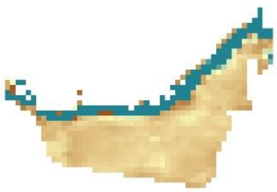


Figure 1: Temperature interpolation 2014

Image Processing

The MODIS aerosol data product for the study period 2006-2015 was acquired from (http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MODAL2_M_AER_OD&date=2016-08-01). The aerosol product in 0.1 degree resolution was cropped for the study area only. Figure 2 shows the derived aerosol product for the year 2014 (others are excluded for brevity).





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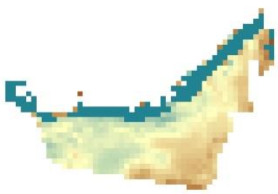
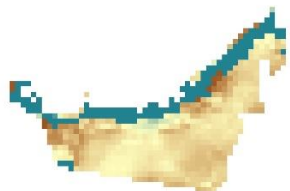
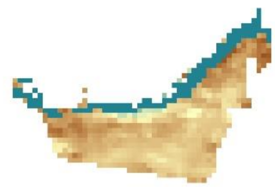
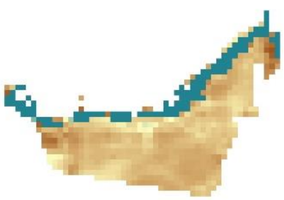
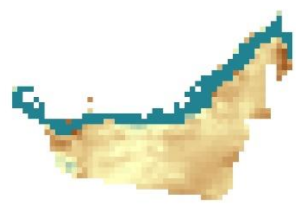


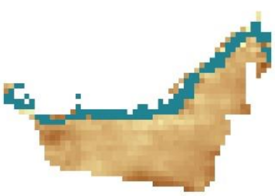




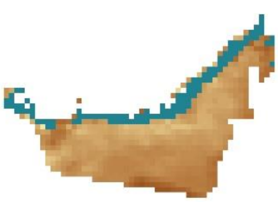
April May June

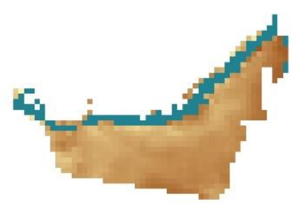


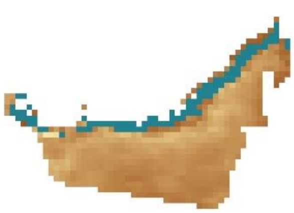




July August September







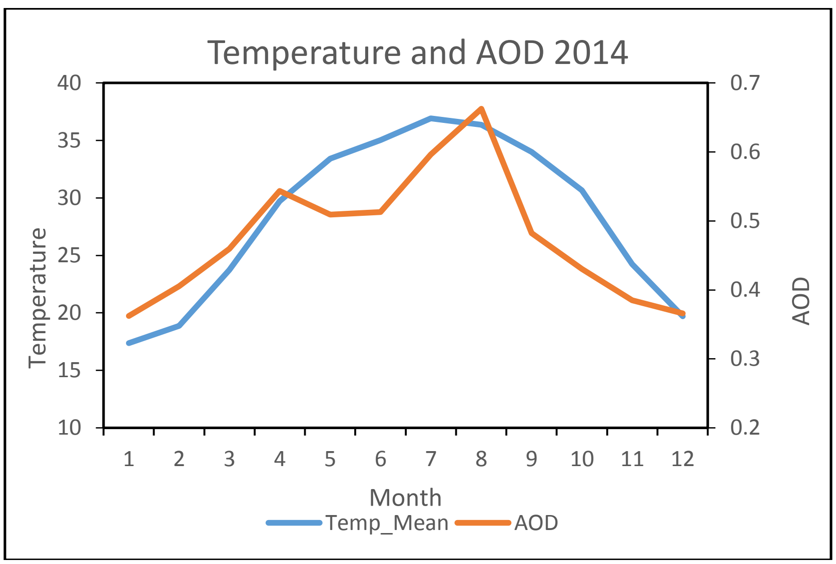
October November December

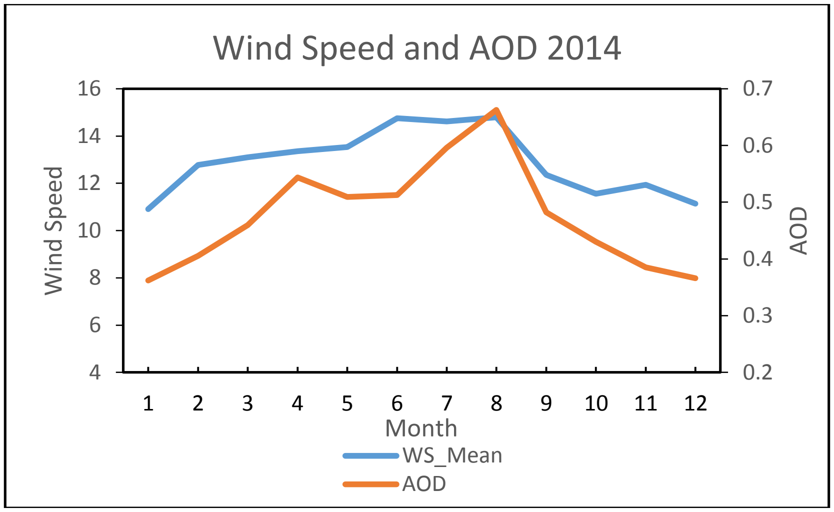
Figure 2: Monthly mean aerosol optical depth 2014

RESULTS AND DISCUSSIONS

Monthly Observations

The mean monthly average temperature, air pressure and wind speed were calculated from the interpolated corresponding layers. In a similar fashion, the mean monthly aerosol optical depth was calculated from the MODIS data. Figure 3 (a-c) show the monthly temperature, wind speed and air pressure along with the AOD for the year 2014. It shows that there is a strong positive correlation between temperature, wind speed and AOD. The rise of temperature and wind speed is associated with a rise in the amount of AOD. This relation was expected should variability of AOD is strongly linked with climatic conditions. In the UAE, particularly in desert environments, the increase or rise in temperature and wind speed lead to the formation of sand storms and sand transport. This in turn leads to the presence of large amount of suspended sand particles in the air.





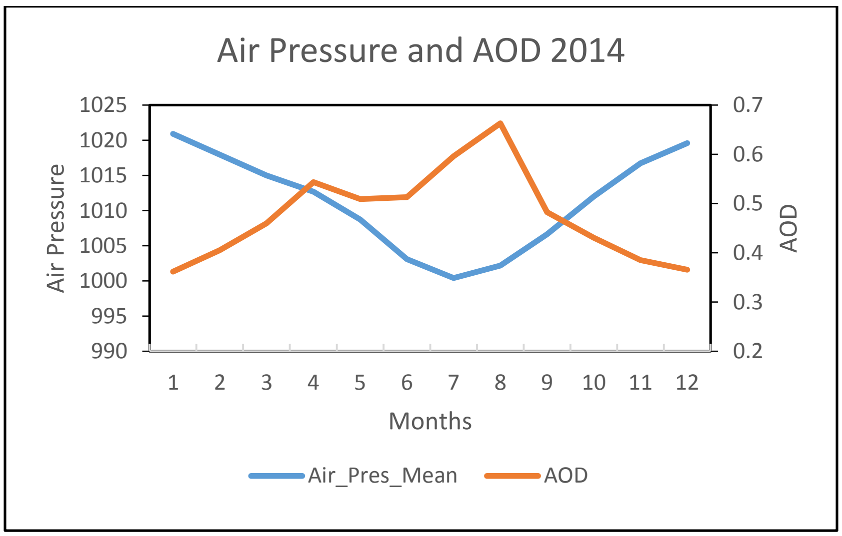


Figure 3(a-c): Temperature, wind speed and air pressure with AOD

Interestingly enough the air pressure and AOD portrays strongly negative relation. This was not expected. The expectation were, should the AOD variability be climatically influenced, that air pressure would have similar relation as temperature and wind speed. Air pressure refers to the force of a column of air on a surface due to its weight. One would thus expect that as such weight increases or decreases the AOD would follow a similar pattern, as atmospheric particles would significantly contribute to the total air weight. At present the authors do not have a scientific explanation to this observation.

<u>Seasonal Observations</u>

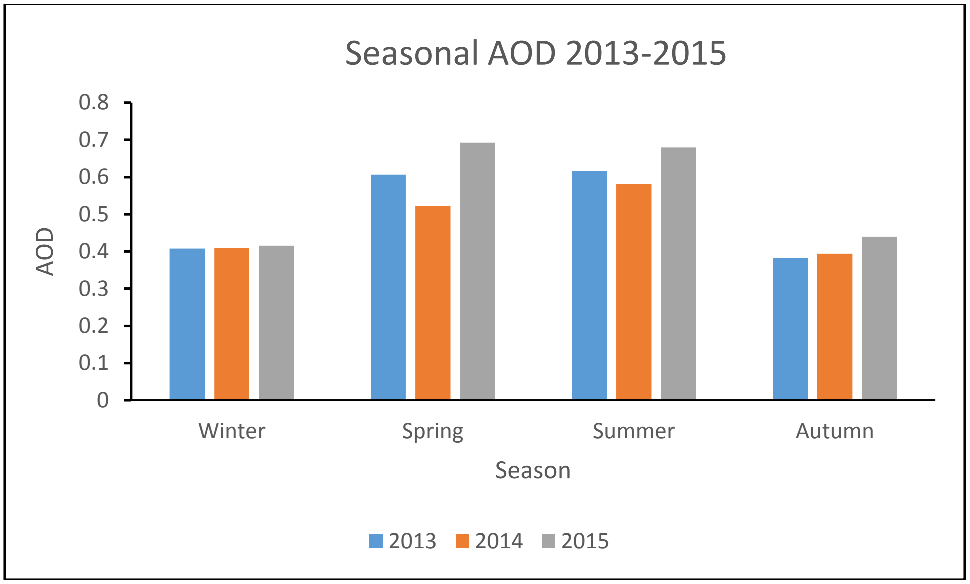


Figure 4: Average Seasonal AOD 2013-2015

Figure 4 shows the average AOD per season for selected years 2013-2015. The results show that the spring and summer seasons are associated with high levels of AOD. Particularly the summer season (July-September). During this season high levels of water vapour dominates the climate due to the intense evaporation from the Gulf waters. This is particularly so, as the geographic regions within the UAE with the highest AOD levels are in close proximity to the coastal areas (Figure 2).

Annual AOD

Figure 5 shows the average annual AOD for each year during the study period. The data does not show any significant difference from year to year. The difference between the minimum average and maximum is about 0.08. It is not possible to generate any trend with merely 10 observations.

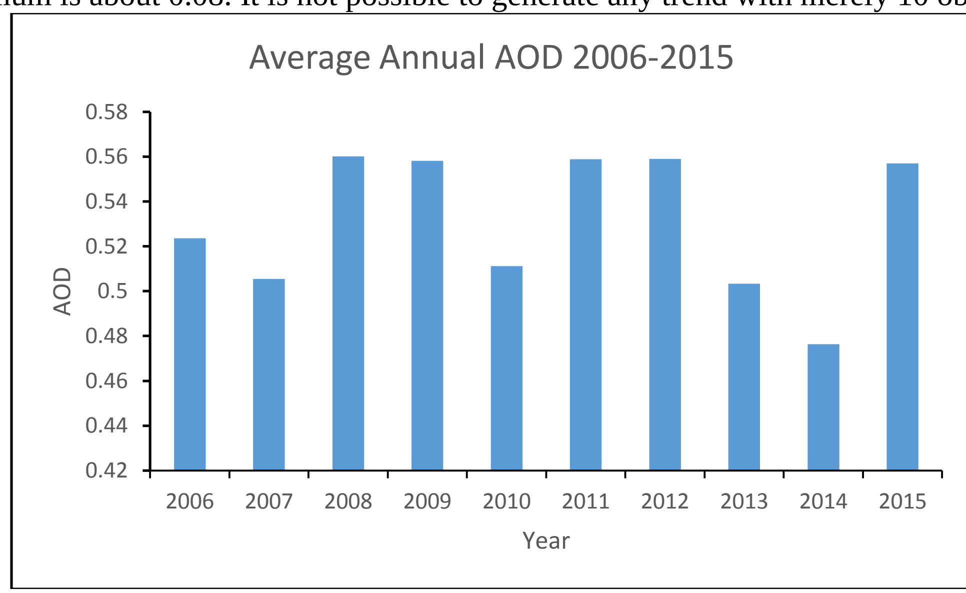


Figure 5: Average annual AOD 2006-2015

Spatial Distribution of AOD in the UAE

The MODIS AOD product portrays quite a diversity in the geographic spatial distribution of AOD over the UAE (figure 2). AOD start to rise by late April along the coastal areas. Note in April 2014, a massive sand storm has hit the western regions of the UAE resulting in abnormal high levels of AOD. AOD levels in the UAE peak in August and this can be observed inlands on the desert surfaces and along the coastal areas. The mountainous regions of the UAE along the borders with Oman display the lowest AOD levels year round. This is not surprising, such regions have little sand particles to transport and further they are at quite a large distance from the Gulf waters.

CONCLUSIONS

This study has investigated the monthly, seasonal and inter-annual variability of AOD levels in the UAE in relation with corresponding meteorological observations of air temperature, wind speed and air pressure. Plots of monthly meteorological observations and estimated AOD display strong positive relation between air temperature, wind speed and AOD. This confirms the initial hypothesis that variability of AOD within the study area is primarily due to climatic and seasonal weather conditions. Variability of these meteorological parameters are associated with corresponding variability in the estimated AOD levels. The relation between air pressure and AOD was found to be inversely related. The seasonal variations of AOD over the UAE indicates that the spring and summer seasons show the highest levels of AOD in comparison to the winter and autumn seasons. High levels AOD in the UAE are mostly geographically distributed along the coastal areas and within the inland open desert surface.

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