A COMPREHENSIVE ANALYSIS OF THE SPATIO-TEMPORAL VARIATION OF SATELLITE-BASED AEROSOL OPTICAL DEPTH IN MARMARA REGION OF TURKIYE DURING 2000-2021

P. Ettehadi Osgouei[1], Ş. Kaya[2]

[1] Department of Communication Systems, Institute of Informatics, ITU, Istanbul, 34469, Turkiye - pettehadi@itu.edu.tr
[2] Geomatics Engineering Department, Civil Engineering Faculty, ITU Ayazaga Campus, ITU, Sariyer, Istanbul 34469, Turkiye - Kayasina@itu.edu.tr

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ABSTRACT:

This study investigates the spatiotemporal variability of the aerosol optical depth (AOD) in the atmosphere over the Marmara region, Turkiye. Long-term satellite observations from MODIS MAIAC AOD data spanning the period from 2000 to 2021 are utilized. Examining the temporal variations in AOD in the Marmara region, it is observed that AOD reaches its peak during spring (May) and summer (August) months, while lower AOD values are observed in winter. Specifically, between August and December, there is a significant decline in monthly mean AOD which is majorly due to particulate removal from the atmosphere via precipitation scavenging. The findings reveal that the inter-annual variability of monthly AOD variations in the Marmara region is primarily influenced by temporary Saharan dust transportation with highest deviations from 22 year averaged AOD in late winters and early springs. The findings from the analysis of seasonal spatial variation of high AOD values revealed that the high AOD area is largest in the summer with about 54% of the total area and then spring (45%) and autumn (26%). Winter has the lowest HVA with 17% of the total area. The seasonal percentage rates of HVA are due to atmospheric conditions and aerosol sources. Larger HVA in summer is due to the increase of farming practices and biomass residue burnings combined with high moisture absorption effects and high temperature. The heating-specific emissions are the main source of anthropogenic emissions over the high AOD areas during the autumn and winter and aerosols are concentrated over the urbanized centres and industrialized zones.

1. INTRODUCTION

Aerosols, which are solid particles suspended in the Earth's atmosphere, have a significant impact on climate, air quality, the environment, and human health. As important components of Earth's climate system, aerosols play a critical role in the planet's energy balance and can indirectly affect cloud formation (Fan et al., 2016; Li et al., 2014). Additionally, atmospheric aerosol pollution significantly affects ambient air, and high concentrations of air pollution are among the major factors responsible for human diseases (Popov et al., 2020; Saygın et al., 2017). Understanding the ways in which aerosols affect climate, the environment, and human health requires a detailed examination. To comprehend how atmospheric aerosols impact climate conditions, it is necessary to characterize aerosol distribution and monitor temporal changes. One commonly used property of aerosols for studying atmospheric aerosol loading and monitoring spatiotemporal changes in atmospheric pollution is Aerosol Optical Depth (AOD). AOD is a unitless parameter that describes the amount of light reflected or absorbed by aerosols throughout an entire air column. It quantifies the vertical concentration of atmospheric aerosols, which can include haze, dust, sea spray, fire smoke, and a mixture of aerosols. Measuring AOD helps in characterizing multiple aerosol types and understanding the role of aerosol particles in precipitation, radiation, and climate forcing (Attwood et al., 2014; Che et al., 2018; Ng et al., 2017). AOD has been validated and studied as the most comprehensive variable for remotely assessing aerosol burden in the atmosphere. Furthermore, AOD has become an important tool for monitoring air pollution due to its reliable correlation with surface particle matter concentrations (Li et al., 2015; Zheng et al., 2017). Higher AOD values indicate a greater amount of aerosol particles in the air, which may suggest areas with higher levels of air pollution. AOD has become a common property of aerosols studied to investigate their multiple impacts.

Monitoring aerosol pollution is crucial for determining its effects and developing mitigation measures. Satellite aerosol data is an invaluable resource for investigating and assessing aerosol pollution on a wide scale, providing spatially extensive information on the distribution and properties of aerosols. Researchers from multiple fields benefit from satellite aerosol datasets. Daily aerosol data from Earth-viewing satellite sensors offer an opportunity to examine the impacts of aerosols on climate systems. The impacts of aerosols differ with the type of aerosol, and thus, the changing composition of atmospheric aerosols due to intensifying industrial activities should be continuously tracked to accurately monitor their effects on climate systems (Quaas et al., 2008). Alterations in aerosol composition mainly modify the impacts of aerosols on cloud condensation nuclei, cloud properties, and precipitation. Therefore, the consistent monitoring of aerosol types using satellite aerosol data makes it possible to study the impacts of aerosols on the water cycle and the world's water supply (Kaufman et al., 2005). The characteristics and distribution of aerosols over the ocean can be different from those over the land. Monitoring the spatial distribution and temporal variation of aerosol loadings over the ocean is as important as those over the land. The independent satellite aerosol retrieval algorithms are proposed to derive the aerosol characteristics over the land and oceans separately (Remer et al., 2002). Satellite aerosol observations have been widely used to study the spatial-temporal distribution of dust loading, particularly over arid and semiarid regions (Song et al., 2018). A satellite aerosol dataset with global spatial coverage has been majorly helpful for tracking the pattern of dust transportation and its effects on regional air pollution (Badarinath et al., 2010; Tao et al., 2021, p. 221).

AOD is a fundamental aerosol property widely employed in the study of aerosols to assess their levels, distribution, and temporal evolution. One of the first sensors created specifically for aerosol remote sensing was the Moderate Resolution Imaging Spectroradiometer (MODIS), which was launched on the Terra and Aqua satellites. Based on earlier research on aerosol remote sensing, MODIS carried developed technologies to improve the accuracy of aerosol parameter retrievals over both the land and ocean surfaces. The MODIS operational aerosol products offer retrievals of AOD utilizing various aerosol retrieval algorithms including the Deep blue (DB) and Dark target (DT) algorithms. Efforts to improve the spatial resolution of AOD retrievals led to the development and application of the Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm using MODIS radiance measurements. The MODIS MAIAC AOD product enables aerosol retrievals at a spatial resolution of 1 km. (Lyapustin et al., 2018). Numerous studies have utilized the latest MODIS aerosol dataset, the MODIS MAIAC AOD product to investigate temporal variations and spatial distributions of aerosols at various scales. The objective of the current study is to utilize the satellite-derived AOD dataset to analyse the monthly and seasonal variations in aerosol loading over one of the densely populated region in Turkiye that experiences aerosol emissions from diverse sources such as industrial activities, human-generated particles, and agricultural aerosols.

2. STUDY AREA

The most populous region in Turkiye is the Marmara Region, situated in the northwest of the country (Figure 1). Although having the second-smallest area among Turkiye's seven geographical regions, it has the most inhabitants. This is mostly because the area contains Istanbul, which, with a population of over 15 million, is not only the biggest metropolis in Turkiye but also one of the biggest cities worldwide. Some other important cities are located in the Marmara region, including Bursa, Kocaeli, and Tekirdag.

Figure 1: Study area. (Image from © Google Earth)

The area is a significant economic center as well, with commercial and industrial activity. In the Marmara region, aerosols are formed from a variety of natural and anthropogenic sources. Aerosols over the Marmara region include sea salt and sprays from the Mediterranean Sea, black sea, and along the Istanbul phosphorus line. In addition, aerosols from agricultural activities, forests, biomass burnings, anthropogenic aerosols from human and industrial activities, maritime transport, and seasonal Saharan dust transportation. The study encompasses the full period for which full months of MODIS MAIAC data were available at the time of writing, i.e. from 2000 until 2021.

3. DATASET

The MAIAC AOD dataset offers AOD retrievals with a spatial resolution of 1 km and a temporal resolution of a day (Lyapustin et al., 2011). Based on the MAIAC algorithm, the L1B MODIS data are gridded to a 1-km resolution where cloud-contaminated pixels are eliminated while smoke/dust pixels are retained (Lyapustin et al., 2018). In the AOD retrieval process the surface reflectance required to be calculated using a variety of viewing and illumination geometries to take into account surface bidirectional reflectance distribution function (BRDF) effects that might result in a large bias in a returned AOD (Hsu et al., 2006). The BRDF is characterized by the MAIAC method using a time series of multi-angle data collected over four days at the poles and 16 days at the equator. The surface reflectance at 0.47 m and 2.13 m is estimated using the Lambertian equivalent reflector (LER) surface model, from which a spectral regression coefficient (SRC) between the surface reflectance (B3/B7) is computed for each observation. The SRC over bright surfaces is computed for additional three-view angles in order to improve surface reflectance estimation. The surface reflectance is estimated at a pixel scale rather than within the 25×25 km windows in the C6 MAIAC algorithm, which reduces the AOD "Blockiness" that is brought on by random SRC bias (Lyapustin et al., 2018). This is one of the algorithm's most significant improvements over earlier iterations. The calculated surface reflectance is compared to the assumed top-of-the-atmosphere reflectance in pre-calculated look-up-tables (LUTs) and the match with minimum residual is used to retrieve the AOD (Levy et al., 2007). Based on eight regional aerosol models that are representative of the AERONET regional climatology, eight LUTs are utilized for aerosol retrievals (Lyapustin et al., 2011). A mesoscale AOD-based cloud mask is used to identify subpixel clouds after the MAIAC AOD retrieval (Alexei Lyapustin et al., 2018). We used daily MODIS MAIAC AOD Level 2 gridded data at 1-km resolution (MCD19A2) acquired between 2000 and 2021 for analysis.

Each tile in the MODIS MAIAC AOD product collection has a Sinusoidal (SIN) projection grid and covers an area of about 1200 km by 1200 km, or roughly 10° latitudes by 10° longitudes at the equator. The Marmara region is covered by 4 tiles of MODIS MAIAC AOD data (h19v04, h19v05, h20v04, and h20v05). There are 2-3 daily observations for each tile acquired by either the Aqua or the Terra satellites. A total of 5627 images per year are averaged and mosaiced for conducting the annual aerosol profile of the Marmara region. The averaging operations are performed per pixel for the "Optical_Depth_055" band of the MCD19A2 V6 data product and "AOD_QA " and “AOD_QA Bitmask” bands of the MCD19A2 V6 data product were applied to mask out poor-quality pixels. The Google Earth Engine (GEE) platform was used to compute the annual average values of AOD and to display the distribution of the averaged AOD over the study region. The tile-based MAIAC processing may result in a discontinuity in the AOD maps presented in this

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work at a line around 35° N (Lyapustin et al., 2018). Local aerosol models adjusted to AERONET climatology are used for aerosol retrieval and atmospheric correction. This leads to satisfactory AOD performance, according to a private communication from A. Lyapustin on October 20, 2021. However, the use of unique aerosol optical properties between the tiles makes the boundaries between the regions obvious if AOD levels are moderately or highly persistent. By the end of 2021, the MAIAC C6.1 re-processing is expected to minimize the gaps between tiles.

4. PROCESSING

4.1 Pre-processing

To examine the spatiotemporal variations of AOD certain criteria were applied to the dataset. Monthly averages were calculated for each location only if at least one-third of the monthly data or a minimum of ten observations were available. The AOD retrieval dataset utilized a 16-bit Quality Assurance (QA) band. To ensure the highest data quality, only the best-quality bitmask derived from the QA band was selected. This analysis specifically focused on AOD over land, excluding AOD measurements over water bodies. Additionally, to mitigate higher biases associated with satellite-derived AODs near coastal areas, a buffer zone of 500 meters was applied to exclude AOD pixels over coastal sites and minimize overestimated AOD values (Ettehadi et al., 2022)

4.2 Methodology

The AOD data were projected to the Universe Transverse Mercator (UTM) projection and clipped using Turkiye's Civil Administration Boundaries as a mask. The clipped data were then aggregated and averaged. Monthly and seasonal averages were calculated using all effective daily data. Additionally, the temporal variations in regions with high AOD values were analysed using a percentile-based approach. In the percentile-based approach used to analyse the distribution of AOD at smaller scales, regions with high AOD values were identified by setting a threshold based on the 85th percentile. This means that areas with AOD values higher than 85% of the observed values were considered as high AOD areas (e.g. high value areas or HVA). The thresholds were calculated considering AOD data for each season between 2000 and 2021.

5. RESULTS

The monthly variabilities of aerosols were investigated over the Marmara region utilizing MODIS MAIAC AOD daily data from 2000 to 2021. Figure 2 shows the monthly mean MODIS MAIAC AOD spatially averaged for the Marmara region, with one standard deviation shown by the dashed lines. The monthly mean AOD values are calculated using the daily AOD data between 2000 and 2021. The monthly mean AOD increases gradually from January to May and fluctuates between May and August and reaches its highest value in August. The monthly mean AOD decreases after August and reaches the lowest monthly mean at the end of the year during December.
The monthly mean MODIS AOD varied from 0.087 (December) to 0.15 (August). The uppermost levels of MODIS MAIAC AOD broadly appeared from May to August ranging from 0.14 to 0.15. The highest AOD showed in August, with monthly means of 0.15±0.02. The standard deviation from the average AOD date between 2000-2021 represents the interannual variability of AOD over the Marmara region for 21 years (dashed lines in Figure 2). While transported dust from arid regions or emissions from severe wildfires create the highest interannual variabilities, persistent regional aerosol emissions have the lowest magnitudes of interannual variability in monthly AOD. Less spread in AOD values shows the relatively simple aerosol source in the period. AOD values vary from year to year in the Marmara region, with February, March, April, and May having the highest interannual fluctuation magnitudes between 2000 and 2021.

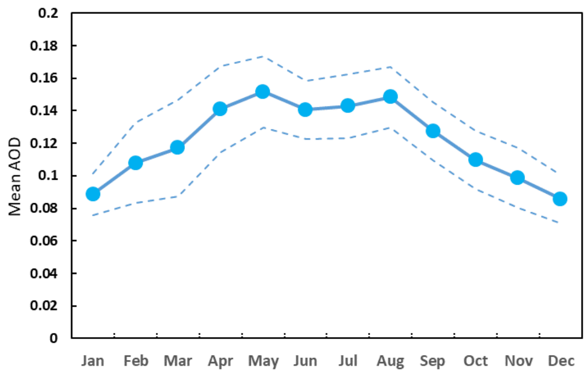

Figure 2: Time series of monthly MODIS MAIAC AOD at 550 nm for the Marmara region during 2000–2021.

Maximum intervariabilities in late-winter and early-spring could be thought of as the periods when the region receives transported dust aerosols. The transported dust could also become mixed with the regional anthropogenic emissions and intensify the aerosol concentration. The Marmara region is vulnerable to dust transport from the Sahara during spring, which is carried by the strong southwesterly flows. Winter is the second season after spring when the region gets dust storms (Baltaci, 2021). One of the highest AOD values over the Marmara region was recorded in February 2015 (AOD > 0.5) which is due to the transported Saharan dust happened.
The highest AOD values were recorded from April to August (Figure 2). The Marmara region's sowing and harvesting seasons last from April through mid-autumn. The aerosol concentration can be increased in many different ways by agricultural activities. The Marmara region is a significant agricultural region in Turkiye and because of its good soil properties, it offers the widest variety of agricultural products. Of all the cultivated land in Turkiye, the Marmara region has the highest proportion of cropland. Though, it is vulnerable to aerosol emissions from agricultural practices. Tilling, land preparation actions, soil cultivation, and harvesting operations are the primary agricultural operations accountable for the formation and release of soil and dust emissions (Katra, 2020). The other farming activity which is a significant factor contributing to the higher AOD mean during summertime and more specifically during August is crop residue or stubble burning. The stubble is the roots and stalks of harvested cereals as a result of agricultural production. Farmers frequently burn stubble because it is seen as a good practice (Ozturk and Bascetincelik, 2006). Even though stubble burning has been outlawed in Turkiye since 1993, it is nevertheless practiced in the majority of Turkiye including the Marmara region. Turkiye's cultivated land area in 2019 was about 15.4 million hectares, excluding fallow land. Aside from the detrimental effects on soil qualities and water resources, stubble burning is one of the biggest causes of air pollution. Uncontrolled burning of stubble specifically during the warm seasons can cause unharvested crops in neighboring fields to burn and they can cause forest

fires. Crop residue burning and increasing heat are the two major causes of forest fires. Out of the 11332.44 ha of land damaged by forest fires in Turkiye just in 2019, 406.45 ha of the land was in the form of fires brought on by stubble burning (Yakupoglu et al., 2022). Looking at the monthly AOD mean trend makes it clear that agricultural stubble burning emissions throughout the months of April to August caused an intensified aerosol concentration in the Marmara region (Figure 2).

Using seasonal AOD records, the interannual variation trends of aerosol loading across the Marmara region are analyzed, and the mechanisms influencing the significant differences between seasonal AOD values are investigated.

To generate the seasonal AOD profile for the Marmara region, we calculated the average AOD for each season between 2000-2021 (Figure 3). The average MODIS MAIAC AOD over the Marmara region with annual mean of 0.123 was highest in summer, with an average value of 0.146, followed by spring and autumn, with average values of 0.137 and 0.113, respectively. The average AOD value decreased to 0.095 in winter, whereas the average AOD in summer was approximately 1.08-1.27 times that in spring and autumn and 1.65 times that in winter.

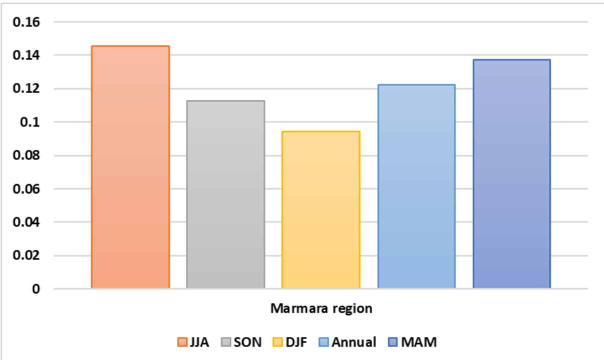

Figure 3: Annual and Seasonal averaged MODIS MAIAC AOD over the Marmara region from 2000 to 2021.

Significant variety can be seen in the spatial distribution of aerosol loading in a given area, with seasonal and monthly variations being particularly noticeable. This irregular distribution draws attention to the temporal dynamics of aerosol concentrations and the necessity of taking seasonal variations into account when analyzing aerosol patterns. During each season, the optical characteristics and intensities of the aerosol loadings can be observed and researched using the satellite-derived AOD information. To quantify and investigate the optical properties of various aerosol types over the Marmara region, both natural and anthropogenic, seasonal monitoring of aerosol load and properties is suggested. The seasonal AOD profiles of the Marmara region are generated between 2000 and 2021 utilizing the daily MODIS MAIAC AOD data. The factors that influence aerosol distribution and magnitude are explored concerning the seasons' potent elements. The spatial distribution of the monthly and seasonal mean AOD are presented in Figure 4 and 5, respectively, where the daily MODIS MAIAC AODs have been averaged over the entire period of study. The spatially averaged AOD value of each month in 22 years ranged from 0.054 to 0.233. The spatial distribution of monthly mean AOD was comparable in all 22 years with higher AOD distributed over the entire study region from late-spring to early-autumn (April-September) (Figure 4).

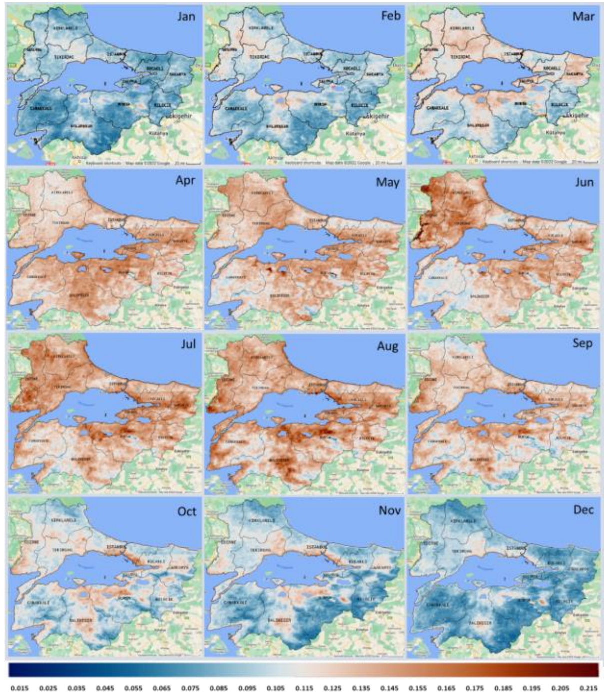

Figure 4: Spatial distribution of mean MODIS MAIAC AOD in each month for the period 2000-2021.

The annual mean AOD spatially averaged for the Marmara region was 0.12±0.02, with an AOD maximum in Summer (0.145±0.004) (Figure 5). Summer was the season with the highest high-value area of the AOD, followed by spring and autumn, while winter had the lowest high-value area. The extent of the elevated AOD area varies with the season and is largest in the summer when it reaches west over the Thrace region. High values of AOD (AODs > 0.135) were found along the coastal area of the Marmara Sea, Aegean Sea, and black sea, while low ones were in the southwest and easternmost parts. Toward the southwest and easternmost, over Çanakkale, Bilecik, and Bursa, the AOD is lower than in the near-coastal areas with areas where the AOD varies between 0.05 and 0.1. The easternmost and southwest part of the Marmara region is the mountainous area, where the emission of anthropogenic aerosols remains at low levels.

Household activities in the Marmara region, home to approximately 27% of Turkiye's total population, can significantly contribute to the region's aerosol loading, impacting air quality in the coastal areas surrounding the Marmara Sea. In addition, the cities near the Marmara Sea, especially those in the North and East Marmara Sea region depend on industrial development economies and therefore have serious aerosol emissions. The region is subjected to increasing human interference in the form of industrial activities. Besides the pollution from various local land-based sources, from the heavily populated and industrialized Istanbul Metropolitan, Bursa, Yalova and Kocaeli, the region is also exposed to the emissions from maritime transport.

The spatial distributions and temporal variations of AOD are partly attributed to seasonal source emission variations. The emissions from non-residential sources of anthropogenic emissions, such as power generation, industry, and transportation, are observed throughout the year. Relatively high AOD is observed over urban and industrial areas during the spring, summer, and autumn, with values of about 0.11-0.18 and lower in the winter.

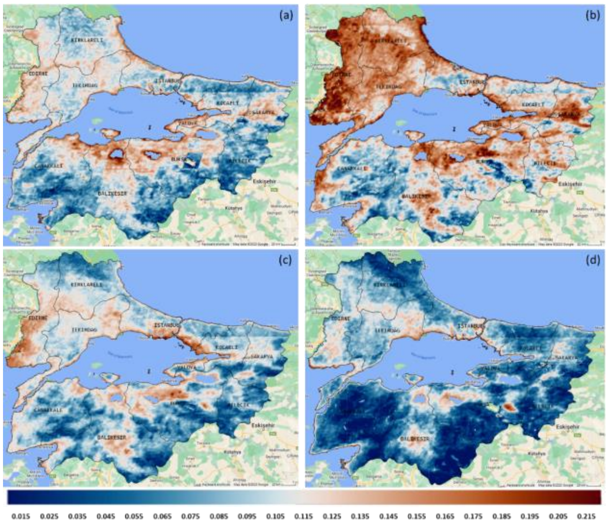

Figure 5: Seasonal mean aerosol distributions for (a) spring (March-May), (b) Summer (June-August), (c) autumn (September-November) and (d) winter (December-Feb) for the period 2000-2021 over the Marmara region.

The heating-specific emissions are the main source of anthropogenic emissions over the high AOD areas during the autumn and winter. The aerosols are highlighted over the urban centers where the population resides during autumn and winter, with higher AODs seen in autumn due to seasonal meteorological conditions. During winters, aerosols are reduced by higher aerosol washouts and dispersed by larger wind speeds over the Marmara region.

The extent of the elevated AOD area to the total area determines the spatially averaged AOD mean for the study area. The greatest to lowest AODs that are visible over an area are included in the averaged AOD of that region. We distinguished between low-value areas (LVA) and high-value areas (HVA) in terms of aerosol loading. The thresholds for the seasonal HVA and LVA were defined using the percentile thresholds. The HVA contains AOD pixels above the 85th percentile threshold of the seasonal means. The high AOD area is largest in the summer with about 54% of the total area and then spring (45%) and autumn (26%). Winter has the lowest HVA with 17% of the total area. The seasonal percentage rates of HVA are due to atmospheric conditions and aerosol sources. Larger HVA in summer is due to the increase of human activities, transportation, and mainly farming practices combined with intense solar radiation, which can lead to increased evaporation. Same as Summers, Springs in Marmara region is for the agricultural activities plus the pollen emissions which lead to larger HVAs. The increasing precipitation level in autumn and winters decrease HVAs which are largely concentrated in urbanized and industrialized spots. The Trakya region is exposed to larger HVAs in all seasons due to atmospheric conditions and aerosol sources. The coal burning for residential and industrialized activities combined with lower precipitation and warmer weather lead to larger HVAs during a year. The Trakya portion of the Marmara Region, as well as Bilecik, exhibit some signs of a continental climate and experience hot, dry summers. Since the soil is dry during this time of year and there hasn't been much rain, the local soil particles have been more thoroughly re-suspended. The Thrace region experiences high AOD in the summer due to persistently high temperatures and little precipitation, with little rain to wash out the region's high AOD in summers.

6. CONCLUSION

Satellite data have substantial potential for environmental studies. One of the most important environmental concepts is air pollution. Evaluation of free-of-charge satellite data for monitoring and controlling atmospheric aerosol emissions is necessary. Satellite observations of aerosol properties provide a valuable source for researchers and decision-makers trying to understand how aerosols change in the long and short term and how they affect the environment. The dataset presents a significant opportunity to investigate the factors that influence aerosol pollution and the impact of aerosols on climate change and society.

The study utilized the Marmara region as a representative area to investigate the potential of satellite-derived aerosol information data in analysing the spatio-temporal variation of aerosol loading. The monthly and seasonal variations in MODIS MAIAC AOD retrievals observed from the MODIS instrument are analysed to gain insights into aerosol distribution and behaviour. The satellite-based long-term monitoring of aerosol loading on a global scale holds significant potential for monitoring aerosol pollution. This valuable information can aid in mitigating air pollution and enhancing our understanding of the causes and primary sources of aerosol emissions in the targeted region. In the Marmara region, there is a noticeable seasonal variation in aerosol pollution. During the warmer months, the region is heavily influenced by aerosols emitted from agricultural practices and biomass residue burning. However, during the colder months, industrialized zones and urban areas experience higher levels of aerosol pollution, mainly attributable to human-generated aerosol emissions. The availability of free satellite aerosol products offers an opportunity to examine aerosol levels, their spatial distribution, and investigate their underlying causes. These findings can be valuable for policy makers in making informed decisions to mitigate aerosol pollution throughout different seasons of the year.

REFERENCES

Attwood, A.R., Washenfelder, R.A., Brock, C.A., Hu, W., Baumann, K., Campuzano-Jost, P., Day, D.A., Edgerton, E.S., Murphy, D.M., Palm, B.B., McComiskey, A., Wagner, N.L., de Sá, S.S., Ortega, A., Martin, S.T., Jimenez, J.L., Brown, S.S., 2014. Trends in sulfate and organic aerosol mass in the Southeast U.S.: Impact on aerosol optical depth and radiative forcing. *Geophysical Research Letters* 41, 7701–7709.

Badarinath, K., Kharol, S.K., Kaskaoutis, D., Sharma, A.R., Ramaswamy, V., Kambezidis, H., 2010. Long-range transport of dust aerosols over the Arabian Sea and Indian region—A case study using satellite data and ground-based measurements. *Global and Planetary Change* 72, 164–181.

Baltaci, H., 2021. Meteorological characteristics of dust storm events in Turkey. *Aeolian Research* 50, 100673.

Che, H., Qi, B., Zhao, H., Xia, X., Eck, T.F., Goloub, P., Dubovik, O., Estelles, V., Cuevas-Agulló, E., Blarel, L., Wu, Y., Zhu, J., Du, R., Wang, Y., Wang, H., Gui, K., Yu, J., Zheng, Y., Sun, T., Chen, Q., Shi, G., Zhang, X., 2018. Aerosol optical properties and direct radiative forcing based on measurements from the China Aerosol Remote Sensing Network (CARSNET) in eastern China. *Atmospheric Chemistry and Physics* 18, 405–425.

Ettehadi Osgouei, P., Roberts, G., Kaya, S., Bilal, M., Dash, J., Sertel, E., 2022. Evaluation and comparison of MODIS and VIIRS aerosol optical depth (AOD) products over regions in the Eastern Mediterranean and the Black Sea. *Atmospheric Environment* 268, 118784.

Fan, J., Wang, Y., Rosenfeld, D., Liu, X., 2016. Review of Aerosol–Cloud Interactions: Mechanisms, Significance, and Challenges. *Journal of the Atmospheric Sciences* 73, 4221–4252.

Hsu, N.C., Tsay, S.-C., King, M.D., Herman, J.R., 2006. Deep Blue Retrievals of Asian Aerosol Properties During ACE-Asia. *IEEE Transactions on Geoscience and Remote Sensing* 44, 3180–3195.

Katra, I., 2020. Soil Erosion by Wind and Dust Emission in Semi-Arid Soils Due to Agricultural Activities. *Agronomy* 10, 89.

Kaufman, Y.J., Remer, L.A., Tanre, D., Li, R.-R., Kleidman, R., Mattoo, S., Levy, R., Eck, T.F., Holben, B.N., Ichoku, C., Martins, J.V., Koren, I., 2005. A critical examination of the residual cloud contamination and diurnal sampling effects on MODIS estimates of aerosol over ocean. *IEEE Transactions on Geoscience and Remote Sensing* 43, 2886–2897.

Levy, R., Remer, L.A., Mattoo, S., Vermote, E.F., Kaufman, Y.J., 2007. Second-generation operational algorithm: Retrieval of aerosol properties over land from inversion of Moderate Resolution Imaging Spectroradiometer spectral reflectance. Journal of Geophysical Research: Atmospheres 112.

Li, J., Carlson, B.E., Dubovik, O., Lacis, A.A., 2014. Recent trends in aerosol optical properties derived from AERONET measurements. *Atmospheric Chemistry and Physics* 14, 12271–12289.

Li, J., Carlson, B.E., Lacis, A.A., 2015. How well do satellite AOD observations represent the spatial and temporal variability of PM2. 5 concentration for the United States? *Atmospheric Environment* 102, 260–273.

Lyapustin, A., Martonchik, J., Wang, Y., Laszlo, I., Korkin, S., 2011. Multiangle implementation of atmospheric correction (MAIAC): 1. Radiative transfer basis and look-up tables. *Journal of Geophysical Research: Atmospheres* 116.

Lyapustin, A., Wang, Y., Korkin, S., Huang, D., 2018. MODIS Collection 6 MAIAC algorithm. *Atmospheric Measurement Techniques* 11, 5741–5765.

Ng, D., Li, R., Raghavan, S., Liong, S.-Y., 2017. Investigating the relationship between Aerosol Optical Depth and Precipitation over Southeast Asia with Relative Humidity as an influencing factor. *Scientific Reports* 7.

Ozturk, H.H., Bascetincelik, A., 2006. Energy Exploitation of Agricultural Biomass Potential in Turkey. *Energy Exploration & Exploitation* 24, 313–330.

Popov, O., Iatsyshyn, A., Kovach, V., Artemchuk, V., Kameneva, I., Taraduda, D., Sobyna, V., Sokolov, D., Dement, M., Yatsyshyn, T., 2020. Risk Assessment for the Population of Kyiv, Ukraine as a Result of Atmospheric Air Pollution. *Journal of Health and Pollution* 10, 200303.

Quaas, J., Boucher, O., Bellouin, N., Kinne, S., 2008. Satellite-based estimate of the direct and indirect aerosol climate forcing. *Journal of Geophysical Research: Atmospheres* 113.

Remer, L.A., Tanré, D., Kaufman, Y.J., Ichoku, C., Mattoo, S., Levy, R., Chu, D.A., Holben, B., Dubovik, O., Smirnov, A., Martins, J.V., Li, R.-R., Ahmad, Z., 2002. Validation of MODIS aerosol retrieval over ocean. *Geophysical Research Letters* 29, MOD3-1-MOD3-4.

Saygın, M., Gonca, T., Öztürk, Ö., Has, M., Çalışkan, S., Has, Z.G., Akkaya, A., 2017. To Investigate the Effects of Air Pollution (PM10 and SO2) on the Respiratory Diseases Asthma and Chronic Obstructive Pulmonary Disease. *Turk Thorac J* 18, 33–39.

Song, Q., Zhang, Z., Yu, H., Kato, S., Yang, P., Colarco, P., Remer, L.A., Ryder, C.L., 2018. Net radiative effects of dust in the tropical North Atlantic based on integrated satellite observations and in situ measurements. *Atmospheric Chemistry and Physics* 18, 11303–11322.

Tao, M., Gui, L., Li, R., Wang, Lili, Liang, S., Li, Q., Wang, Lunche, Yu, C., Chen, L., 2021. Tracking prevailing dust aerosol over the air pollution in central China with integrated satellite and ground observations. *Atmospheric Environment* 253, 118369.

Yakupoglu, T., Dindaroğlu, T., Rodrigo-Comino, J., Cerdà, A., 2022. Stubble burning and wildfires in Turkey considering the Sustainable Development Goals of the United Nations. *Eurasian Journal of Soil Science (EJSS)* 11, 66–76.

Zheng, C., Zhao, C., Zhu, Y., Wang, Y., Shi, X., Wu, X., Chen, T., Wu, F., Qiu, Y., 2017. Analysis of influential factors for the relationship between $PM_{2.5}$ and AOD in Beijing. *Atmospheric Chemistry and Physics* 17, 13473–13489.