Research Article *Araştırma Makalesi* DOI: 10.5281/zenodo.15739554

Analysis of Absorbing Aerosols for Ground-Based Astronomical Observatories in Türkiye

Türkiye'deki Yer Tabanlı Astronomi Gözlemevleri için Soğurucu Aerosollerin Analizi

Sima AYDIN
Atatürk University, Faculty of Science, Department of Astronomy and Space Sciences, Erzurum, Türkiye

Fethullah POLAT
Atatürk University, Faculty of Science, Department of Astronomy and Space Sciences, Erzurum, Türkiye

Kazım KABA
Atatürk University, Faculty of Science, Department of Astronomy and Space Sciences, Erzurum, Türkiye

Abstract

In this study, the impact of aerosols on ground-based astronomical observations in Türkiye was examined, and their spatial and temporal variations were assessed. Satellite data was used in the study due to its advantage of wide area coverage. The absorbing aerosol index (AAI) product, derived from multi-sensor observations, was used in the research. Positive AAI (PAAI) is a measurement of the concentration of absorbing aerosols (such as dust, smoke, volcanic ash, etc.) in the atmosphere. High PAAI values are often indicative of significant weather events, such as dust storms, forest fires, and volcanic eruptions. Therefore, PAAI data can serve as an important indicator for atmospheric conditions affecting astronomical observations. PAAI values can provide significant insights into the evaluation of the accuracy of astronomical observation data, the planning of observation programs, and selection of suitable observation sites. Understanding the impact of atmospheric aerosols on photometric and spectroscopic data is critical for improving the success of future high-precision astronomical observations. The present study reveals the current aerosol characteristics of the observatories in detail. The global average PAAI value for 2024 is calculated to be 0.34, which is lower than the 45-year long-term global average of 0.38. However, the average PAAI value for Türkiye in 2024 was 0.39, which is consistent with the long-term global average. These findings indicate that the observatories in Türkiye are closely aligned with the global average aerosol conditions.

Keywords: Absorbing Aerosol Index, Astronomy, Remote Sensing, Spatiotemporal Analysis, Türkiye

Öz

Bu çalışmada, Türkiye'deki yer tabanlı astronomik gözlemevleri için, aerosollerin mekânsal ve zamansal değişimleri değerlendirilmiştir. Çalışmada geniş alanları kapsaması nedeniyle uydu verileri tercih edilmiş, çoklu sensör gözlemlerinden türetilen soğurucu aerosol indeksi kullanılmıştır. İndeksin pozitif değerleri, atmosferdeki ışığı soğuran aerosollerin (toz, duman, volkanik kül gibi) yoğunluğunu ölçen bir parametredir. Yüksek indeks değerleri, genellikle toz fırtınaları, orman yangınları ve volkanik patlamalar gibi büyük ölçekli atmosferik olayların varlığını göstermektedir. Bu nedenle, bu veriler astronomik gözlemler için atmosferik koşulların belirlenmesinde önemli bir gösterge olarak kullanılabilir. Aerosol değerleri, astronomik gözlem verilerinin doğruluk düzeylerinin değerlendirilmesi, gözlem programlarının planlanması ve uygun gözlem yerlerinin seçimi açısından önemli katkılar sunabilir. Atmosferik aerosollerin fotometrik ve spektroskopik veriler üzerindeki etkilerinin anlaşılması, gelecekteki yüksek hassasiyetli astronomik gözlemlerin başarısını artırmak için kritik öneme sahiptir. Bu çalışma ile Türkiye'deki gözlemevlerinin mevcut aerosol özellikleri ayrıntılı biçimde ortaya konmuştur. 2024 yılı için küresel ortalama aerosol değeri 0.34 olarak hesaplanmış ve bu değer 45 yıllık uzun dönem küresel ortalama olan 0.38'in altında bulunmuştur. Öte yandan, Türkiye'nin 2024 yılı ortalama aerosol değeri 0.39 olarak ölçülmüş ve uzun dönem küresel ortalama ile uyumlu olduğu belirlenmiştir. Bu bulgular, Türkiye'deki gözlemevlerinin, atmosferik aerosol koşulları açısından dünya ortalamasına yakın değerlere sahip olduğunu göstermektedir.

Anahtar Kelimeler: Soğurucu Aerosol İndeksi, Astronomi, Uzaktan Algılama, Mekansal-Zamansal Analiz, Türkiye

Sorumlu Yazar/Corresponding Author:
Sima Aydın
E-mail: simaaydin20@gmail.com

Geliş Tarihi/Received 28.04.2025
Kabul Tarihi/Accepted 19.06.2025
Yayın Tarihi/ Publication Date 27.06.2025

Cite this article
Aydın, S., Polat, F., & Kaba, K. (2025) Analysis of Absorbing Aerosols for Ground-Based Astronomical Observatories in Türkiye. *Journal of Anatolian Physics and Astronomy*, 4(1), 38-50.

Introduction

Atmospheric aerosols (AA), defined as tiny particles suspended in the atmosphere, are a critical factor influencing the quality of observations at ground-based astronomical observatories. These tiny suspended particles, which include dust, soot, sea salt, and organic matter, interact with incoming electromagnetic radiation, causing scattering and absorption that reduce the clarity and accuracy of astronomical data. In particular, aerosols affect the extinction of light, sky brightness, and seeing conditions, which are essential parameters for high-resolution imaging and spectroscopy (Sánchez et al., 2007; Zhang et al., 2013; Mikhalev et al., 2019).

The impact of aerosols on optical and near-infrared wavelengths is of particular significance, because the scattering effects of these particles can significantly reduce the signal-to-noise ratio of faint celestial objects. Additionally, aerosol-related phenomena, such as Rayleigh and Mie scattering, result in wavelength-dependent distortions, which complicate data calibration and interpretation. The geographical location of observatories, including altitude, proximity to urban areas, and local meteorological conditions, plays a key role in determining aerosol concentrations and their optical properties (Sánchez et al., 2007; Zhang et al., 2013; Mikhalev et al., 2019).

Aerosols play a significant role in the diffusion of artificial light, contributing to the increased brightness of the night sky, which consequently diminishes the contrast of celestial objects against the sky (Cavazzani et al., 2020; Kocifaj and Bará, 2020). The diffusion process is influenced by the dimensions, shape, and composition of the aerosol particles. Deviations in the shapes of aerosol particles can substantially modify the spectral and angular properties of scattered light, thereby affecting observational results. The transparency of the atmosphere is a crucial factor in astronomical observations, and the presence of aerosols can significantly impact this transparency. Aerosols, by their nature, absorb and scatter incoming light, leading to increased extinction and decreased signal-to-noise ratios in collected data. Atmospheric aerosols are among the most significant parameters to be monitored in modern ground-based astronomy because of their potentially adverse impacts on observations. To summarize, the presence of atmospheric aerosols has been determined to have a substantial influence on ground-based astronomical observations, given their capacity to affect night sky brightness and atmospheric transparency. It is vital, therefore, that continuous monitoring and analysis of aerosol properties be performed in order to minimize their impact and ensure the accuracy of astronomical data.

The study of atmospheric aerosols is an area of research that is cross-disciplinary, covering aspects of physics, chemistry, atmospheric sciences and astronomy. It is therefore crucial to accurately determine the temporal and spatial variations of atmospheric aerosols. Various techniques are employed for the measurement of aerosols, including ground-based monitoring, aircraft sampling, and remote sensing. Ground-based monitoring frequently employs instruments such as sun photometers, which are commonly used to measure aerosol properties at specific locations (Holben et al., 1998; Verma et al., 2019). The use of remote sensing from satellites, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS), facilitates the acquisition of aerosol data on a large scale, thereby providing invaluable insights into the spatial and temporal aspects of aerosol distribution (Jackson et al., 2013; Levy et al., 2007; Remer et al., 2005).

In this regard, there are many valuable studies that use aerosol data in the literature. For example, Yoshioka et al. (2005) conducted a study on the effects of vegetation change and human land use on dust sources in North Africa, by absorbing aerosol index data. Balarabe et al. (2016) compared the temporal and spatial variability of the monthly mean aerosol index obtained from the OMI in Nigeria during the period 1984 - 2013. Kooreman et al. (2020) conducted a study to investigate the effects of clouds on the absorbing aerosol index at both small and large scales. Liu et al. (2020) conducted a study into the relationship between aerosol optical depth (AOD) and land use, as well as vegetation, in Central Asia using MODIS aerosol data. Shaylor et al. (2022) conducted a twenty-year (2001-2020) AOD assessment for Australia using MODIS data. Jiadan et al. (2023) investigated the spatiotemporal changes in AOD over Ukraine during the Russia-Ukraine war. Gan et al. (2024) conducted an analysis of the characteristics and changes in the three-dimensional spatial and temporal distribution of aerosol types in Central Asia using the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) data from 2007 to 2021. Furthermore, a significant number of studies have been conducted on the subject of aerosol in Türkiye. Ozdemir et al. (2020) utilised aerosol classification methodologies based on AERONET products in the Eastern Mediterranean and Black Sea regions. Tutsak and Koçak (2020) conducted a study of the optical and microphysical properties of aerosols in the Eastern Mediterranean with the objective of distinguishing between different types of aerosols. Tuygun and Elbir (2020) conducted a long-term temporal analysis of the relationship between the AOD, and surface aerosol concentration, and the planetary boundary layer height along the southern coastline of Türkiye. Aslanoğlu et al. (2022) conducted a study of the dust climatology of the Eastern Mediterranean Basin utilising products derived from CALIPSO observations. Tariq et al. (2023)

analysed the AOD and dominant meteorological factors during the summer in Türkiye using remote sensing data. Osgouei and Kaya (2023) presented a comprehensive analysis of the spatiotemporal variation of satellite-based AOD in the Marmara Region of Türkiye between 2000 and 2021. Tuygun and Elbir (2023) investigated the long-term spatial and temporal variations in the atmospheric aerosol properties over Türkiye by reanalysis data from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2). Tuygun and Elbir (2024) analysed of Copernicus Atmosphere Monitoring Service (CAMS) and AERONET data for the Eastern Mediterranean region. Işık et al. (2024) presented a long-term analysis of the MODIS and AERONET AOD data.

In this study, we examined of absorbing aerosols for the ground-based astronomical observations in Türkiye by reviewing their spatial and temporal variability. The study used satellite data, which is advantageous due to its wide area coverage. In this regard, the absorbing aerosol index (AAI) product, derived from multi-sensor observations, was employed. Consequently, this study represents a novel contribution to the scientific community in Türkiye by examining the absorbing aerosol time series of the observatory sites and using Positive AAI (PAAI) data for astronomical purposes for the first time. The study reveals the current aerosol properties of the observatories in detail. However, it is important to note that Türkiye is a neighboring country to the Sahara Desert, the world's largest aerosol/dust source, and is therefore affected by the dust transportation from the desert. Consequently, there is a necessity for more intensive monitoring and management of aerosols for the purpose of improving our understanding of climate, weather, air quality, agriculture and astronomy.

Data Sources and Methodology

This study investigates the aerosol values of major ground-based astronomical observatories in Türkiye during the period 1979-2024. Figure 1 and Table 1 provide coverage and information about the observatories that are of particular significance in this context. Türkiye is located between 26-45 east longitude and 36-42 north latitude, and consists of seven regions. The examined observatories differ in altitude and location, and cover six geographical regions of Türkiye.

The study used monthly average AAI data were obtained from multiple sensors. The multi-sensor AAI (MS-AAI) data comprise AAI data from the TOMS, GOME-1, SCIAMACHY, OMI, GOME-2A, GOME-2B and GOME-2C instruments (see Table 2). The dataset under consideration covers the period from 1978-November to the present, with the current software version being 1.9. The data demonstrate global coverage, with a pixel resolution of 1 degree (~100 km) (https://www.temis.nl/airpollution/absaai/#MS_AAI). The presence of highly absorbing aerosols in the Earth's atmosphere is indicated by the AAI. The most prevalent aerosol types in the AAI are desert dust and biomass-burning aerosols. The AAI data were calculated from reflectances measured at 340 and 380 nm by GOME-1, SCIAMACHY and GOME-2, and from reflectances measured at 354 and 388 nm by OMI (https://www.temis.nl/airpollution/absaai/).

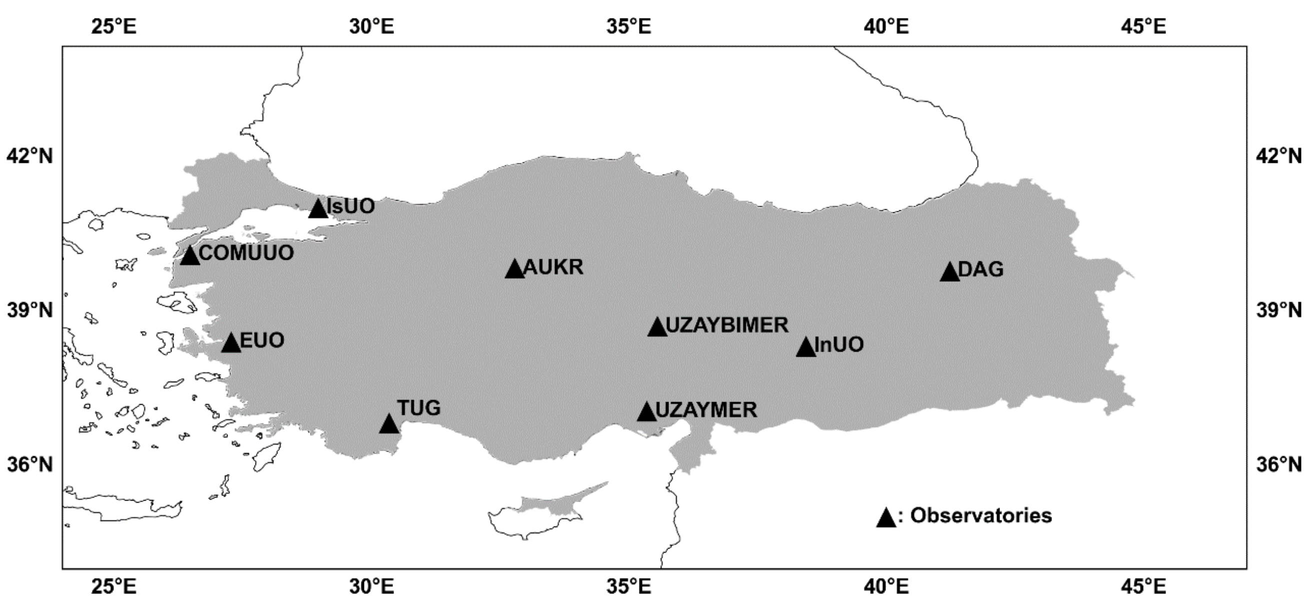

Figure 1 Spatial distribution of major ground-based astronomical observatories in Türkiye.

Table 1 Information of major ground-based astronomical observatories in Türkiye.

Observatory Site	City	Latitude (Degree)	Longitude (Degree)	Elevation (Meter)
Ankara University Kreiken Observatory (AUKR)	Ankara	39.84	32.78	1261
Çanakkale Onsekiz Mart University Ulupınar Observatory (COMU UO)	Çanakkale	40.10	26.48	397
Eastern Anatolia Obsevatory (DAG)	Erzurum	39.78	41.23	3144
Ege University Observatory (EUO)	İzmir	38.40	27.28	787
İnönü University Observatory (InUO)	Malatya	38.32	38.44	1013
İstanbul University Observatory (IsUO)	İstanbul	41.01	28.97	59
TÜBİTAK National Observatory (TUG)	Antalya	36.83	30.34	2461
Astronomy and Space Sciences Observatory Application and Research Center (UZAYBİMER)	Kayseri	38.71	35.55	1105
Space Sciences and Solar Energy Research and Application Center (UZAYMER)	Adana	37.06	35.35	125

The AAI is an index based on the comparison of measured UV reflectances with simulated Rayleigh reflectances. The simulated reflectances are calculated for an atmosphere that is both cloud-free and aerosol-free. The AAI is derived from a value termed “residue”, r, which is defined as follows (Tilstra et al., 2010). In the equation, the superscripts 'obs' and 'Ray' refer to measured and modelled reflections, respectively. The letter 'λ' is used to denote the first member of the wavelength pair (i.e. the shorter wavelength, 340 nm). It is hypothesized that the surface albedo employed in the simulations at this wavelength is equivalent to the surface albedo at the second wavelength, 380 nm. The surface albedo at 380 nm was determined by requiring the simulated reflectance to be equal to the measured reflectance at this wavelength (Tilstra et al., 2010). Positive r values in the equation are indicate the presence of absorbing aerosols, while negative or zero r values indicate their absence. Positive values of *r* are defined as PAAI (Tilstra et al., 2010).

$$r = -100\log\left(\frac{R_\lambda^{obs}}{R_\lambda^{Ray}}\right) \quad (1)$$

Table 2 Satellite and sensor information used in producing aerosol product.

Platform	Agency	Instrument	Launch date	End of life date	Resource
Nimbus-7	NASA	TOMS, others	1978	1995	https://www.eoportal.org/satellite-missions/nimbus-7
ERS-2	ESA	GOME, others	1995	2011	https://www.eoportal.org/satellite-missions/ers-2
ENVISAT	ESA	SCIAMACHY, others	2002	2012	https://www.eoportal.org/satellite-missions/envisat
AURA	NASA, others	OMI, others	2004	Operational	https://www.eoportal.org/satellite-missions/aura
METOP-A	ESA, others	GOME-2, others	2006	2021	https://www.eoportal.org/satellite-missions/metop
METOP-B	ESA, others	GOME-2, others	2012	Operational	https://www.eoportal.org/satellite-missions/metop

TEMIS is a web-based service that facilitates the browsing and downloading of atmospheric satellite data. The satellite data products consist primarily of tropospheric trace gases and aerosol concentrations, but also encompass UV products, cloud information and surface albedo climatology. The satellite instruments used for these data sets were GOME, GOME-2, SCIAMACHY and OMI (https://www.temis.nl/intro.php). This study presents a data analysis of PAAI data with global coverage and a long temporal archive. Maps, tables, graphs and basic statistical indexes were used to illustrate the spatial and temporal analysis of the data. The data are presented as monthly averages, with a length of 528 months. In this study, time series methods were used for data analysis.

In this study, the monthly average absorbing aerosol index data obtained were analysed in both spatial and temporal dimensions. The analysis process can be divided into two main stages: firstly, spatiotemporal analysis to reveal spatial-temporal patterns; and secondly, time series analysis to determine long-term changes in the observatory locations. The global and Türkiye spatial distribution patterns for 2024 were created, and principal statistics were extracted. In the second stage of the study, time series were created for the astronomical observatories. Initially, the monthly, seasonal and annual variations of the series under consideration were subjected to rigorous examination, followed by the implementation of time series analysis utilising the monthly data. In this regard, the process entailed the separation of trends, seasonality and irregular components, followed by a thorough evaluation of the trends. The data processing, analysis and visualisation steps were performed utilising the Python programming language

Result and Discussion

Ground-based astronomical observations are of critical importance for understanding the nature of the universe and collecting important data on cosmological processes. However, such observations are vulnerable to the effects of physical and chemical processes in the atmosphere. In particular, aerosols in the atmosphere have the capacity to greatly affect the optical quality and accuracy of observations. Aerosol particles have the capacity to scatter, absorb and re-emit light from the Sun and other astronomical sources. These processes are critical factors that directly affect the quality of the photometric and spectroscopic data obtained at ground-based observing site.

Astronomical observatories in the Türkiye were determined as the study area. The dataset used in this study covers the period 1979-2024 (45 years). Using this large data archive, an average global and Türkiye PAAI map for 2024 year was created. This global map is shown in Figure 2 upper panel and the map of Türkiye, which is a sub-area of this map, is shown in the lower panel in the figure with values normalised to the range 0 - 1. The principal statistical values of the maps are presented in Table 3. PAAI is a measurement of the concentration of absorbing aerosols (dust, smoke, volcanic ash, etc.) in the atmosphere. The presence of high PAAI values are a reliable indicator of significant weather events, including dust storms, forest fires, and volcanic eruptions. The color dark blue on the map indicates a low aerosol concentration, whereas the red-maroon denotes high concentration.

The regions with the highest PAAI (i.e. of most severe conditions) are as follows: West Africa (particularly the Sahara Desert) due to dust, West Central Africa (i.e. the Congo Basin) due to biomass burning and forest fires in general, the Middle East and Central Asia due to drought and wind-blown agricultural soils, northern India and eastern China due to intense human activities, smoke and industrial pollutants, and the Amazon and parts of South America associated with dry season fires. Low PAAI regions (i.e. regions exhibiting optimal conditions) include southern South America, Chile and Argentina, inland Australia, parts of southern Africa, Greenland, Antarctica, the Arctic regions, and extensive areas of the Pacific and Atlantic oceans. The optimal conditions for ground-based astronomical observatories are characterized by a low PAAI, i.e., a clean, absorbing aerosol-free atmosphere. It has been determined that the Atacama Desert in Chile, Hawaii, Namibia (where levels of PAAI are comparatively low), and the Canary Islands (where medium levels of PAAI occur, and occasional effects from Saharan dust may be experienced) are all areas that offer optimal observation opportunities. The regions that present significant challenges (i.e. high PAAI) include northern India and central Africa (e.g. Congo and Chad), as well as eastern China. In summary, low PAAI values are particularly evident on the map in the western slopes of the Andes (on the Chilean side), Hawaii, southern Namibia, and certain inland regions of Australia. In order to facilitate the collection of scientific observations (particularly those derived from optical and infrared telescopes), it is crucial to incorporate PAAI maps as a complement to existing resources such as maps detailing cloud cover, humidity, and light pollution.

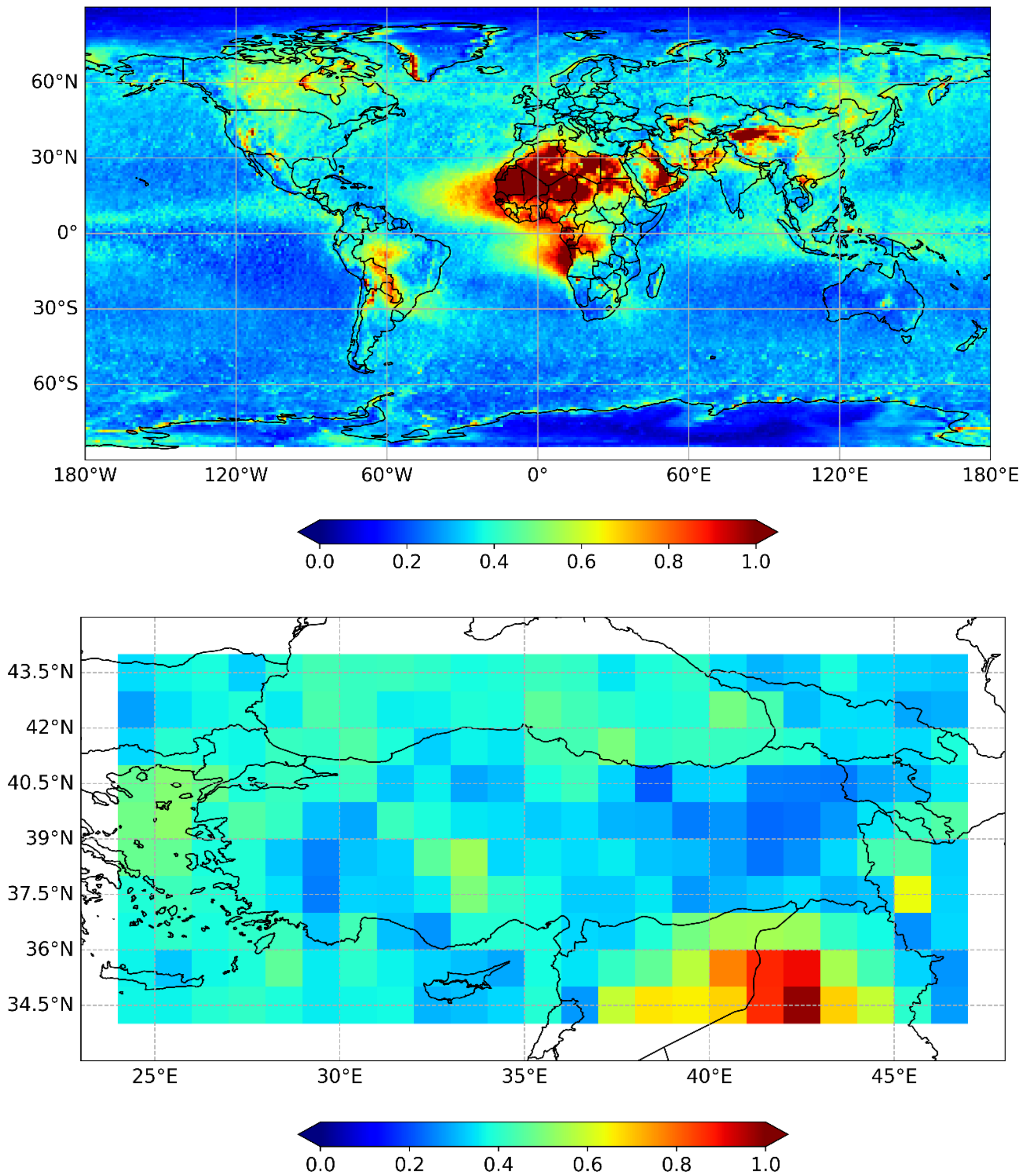

Figure 2 Global and Türkiye mean PAAI maps for 2024.

Table 3 Statistical values of the 2024 mean PAAI maps

	Minimum	Maximum	Mean	Median	Standart Deviation
Türkiye	0.21	0.98	0.39	0.37	0.11
Global	0.02	2.48	0.34	0.31	0.17

PAAI values are of critical importance in the context of optical and infrared observations, given that they serve as a reliable indicator of the extent to which the atmosphere is affected by absorbing aerosols. Upon examination of the PAAI map of Türkiye, it is evident that regions exhibiting low PAAI values (0.0 - 0.3) (indicated in blue and light blue) are particularly conducive to sky observation. Conversely, medium-level PAAI values (0.3 - 0.6) may, on occasion, give rise to certain challenges in the southern region of Central Anatolia, the eastern Mediterranean region, and the westernmost region of the Southeast. High PAAI (>0.6) values were observed in the region surrounding Şanlıurfa, Mardin, and the Syrian border, where dust transport and dense aerosols make the area unsuitable for optical observation. TUG has a light blue value of 0.2–0.3 on the map and is considered to be suitable in terms of atmospheric conditions. However, it is occasionally affected by Saharan dust. As illustrated DAG in the map, light blue and blue values ranging from 0.1 to 0.3 are indicative of relatively low intensity. The DAG site is advantageous in terms of aerosols and has a suitable atmospheric environment for optical and infrared observations. As demonstrated on the EUO map, there is an occurrence of moderate levels of aerosols in light blue and greenish (0.3 – 0.4) values. However, sea effect may result in rapid atmospheric cleaning at the site. The EUO site is generally considered suitable, although it should be noted that on certain days, the quality of observation may be reduced. As illustrated in the IsUO map, light blue values ranging from 0.2 to 0.3 are evident. COMUUO has light blue and green (0.3–0.4) values on the map. In summary, DAG can be classified as very good, TUG and COMUUO as good, and EUO and IsUO as moderate in terms of PAAI. The Southeastern Anatolia Region, particularly the Şanlıurfa–Mardin line, is considered to be at high risk with regard to PAAI. The presence of dust and local aerosols from Syria has been observed in this region. The central Black Sea and the east of Eastern Anatolia are notable for low PAAI, but meteorological conditions and cloudiness should also be considered in these regions. The global average PAAI value for 2024 is calculated as 0.34, which is lower than the 45-year long-term average of 0.38. However, the Türkiye average for 2024 is 0.39, which is nearly equivalent to the long-term global average.

The long-term monthly average graphs for observatories, Türkiye and the global values are presented in Figure 3, and the primary statistics associated with these data are provided in Table 4. An analysis of the graphs indicates that the highest aerosol values are generally observed in Türkiye, UZAYBİMER, COMUUO, IsUO and TUG sites. Conversely, the lowest aerosol values were observed in the EUO, Global, and DAG areas. Furthermore, the high values of the locations under consideration occurred approximately during the April-July period. It is evident that, due to the close proximity of Turkish terrain to deserts and the transportation of dust, high PAAI values are observed during the months when the deserts are active. While values at TUG were recorded at levels above the Türkiye average for the initial six months of the year, values at DAG were comparatively lower. The values of the DAG site exhibit a peak during the period from December to April, with a decrease in the other months.

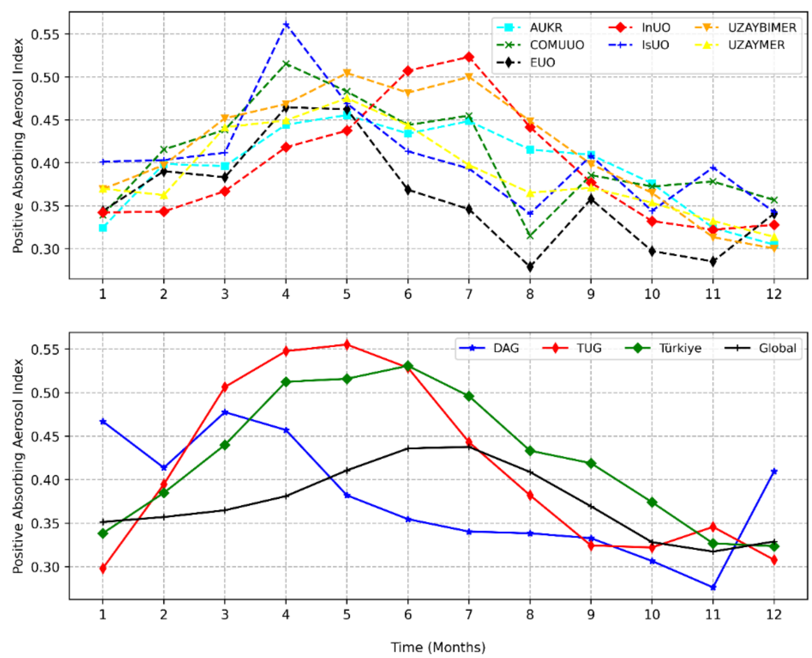

Figure 3 Long-term monthly mean PAAI values for the observatories.

Table 4 Statistical values of the long-term monthly mean PAAI.

Index / Site	Count	Mean	Std	Min	25%	50%	75%	Max
AUKR	12	0.39	0.05	0.30	0.36	0.40	0.44	0.46
COMUUO	12	0.41	0.06	0.32	0.37	0.40	0.45	0.52
DAG	12	0.38	0.07	0.28	0.34	0.37	0.42	0.48
EUO	12	0.36	0.06	0.28	0.33	0.35	0.39	0.46
InUO	12	0.39	0.07	0.32	0.34	0.37	0.44	0.52
IsUO	12	0.41	0.06	0.34	0.38	0.40	0.41	0.56
TUG	12	0.41	0.10	0.30	0.32	0.39	0.51	0.56
UZAYBIMER	12	0.42	0.07	0.30	0.37	0.42	0.47	0.50
UZAYMER	12	0.39	0.05	0.31	0.36	0.37	0.44	0.48
TUR	12	0.42	0.08	0.32	0.37	0.43	0.50	0.53
Global	12	0.37	0.04	0.32	0.35	0.37	0.41	0.44

(Std: Standard deviation, Min: Minimum, Max: Maximum)

Figure 4 shows the bar plots of long-term seasonal PAAI values for the sites and statistical values of the plots can also be seen in Table 5. For all study regions, high aerosol values are observed in spring and summer seasons and low aerosol values are observed in fall and winter seasons. In the spring period, high aerosol values were observed at TUG, COMUUO, IsUO and UZAYBIMER sites, while low aerosol values were observed at InUO, AUKR, DAG and EUO sites. During the summer period, high aerosol levels were recorded in the InUO, UZAYBIMER, TUG and AUKR sites, while low aerosol levels were observed in the DAG, EUO and IsUO sites. During autumn, EUO and DAG sites demonstrated low aerosol levels, while other locations exhibited comparable and lower values. During the winter period, the locations exhibited low and comparable values. The PAAI dataset provides important information for understanding regional and global aerosol distribution and monitoring air quality. Monthly and annual variations of aerosol levels in different regions of Türkiye are critical in determining the extent to which observations are affected by atmospheric disturbances. It shows in detail the annual and seasonal averages of aerosol concentrations in specific regions. High aerosol averages are associated with the mixing of desert dust into the atmosphere, especially in desert regions. The average values of observation points in Türkiye vary depending on local environmental and meteorological factors. This information is important for monitoring and managing air quality.

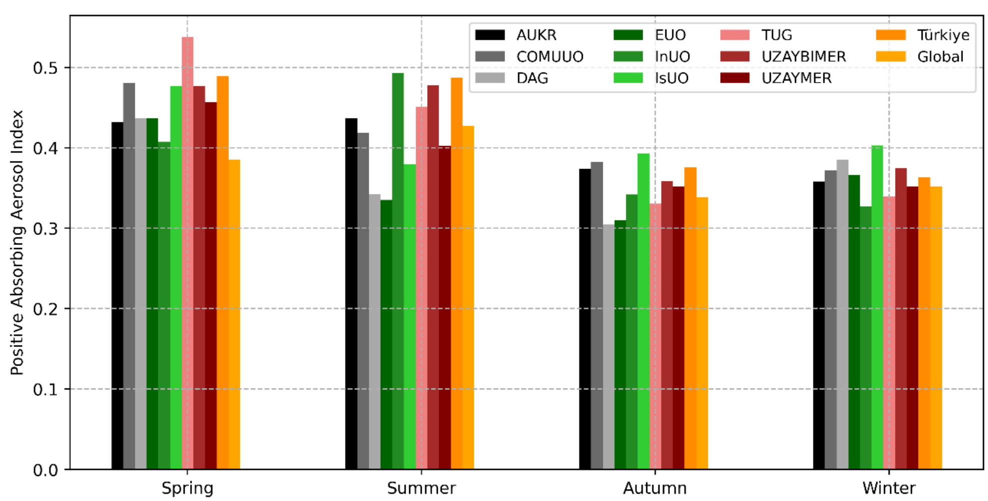

Figure 4 Long-term seasonally mean PAAI values for the observatories.

Table 5 Statistical values of the long-term seasonally mean PAAI.

Season / Site	Spring	Summer	Autumn	Winter
AUKR	0.43	0.44	0.37	0.36
COMUUO	0.48	0.42	0.38	0.37
DAG	0.44	0.34	0.30	0.39
EUO	0.44	0.34	0.31	0.37
InUO	0.41	0.49	0.34	0.33
IsUO	0.48	0.38	0.39	0.40
TUG	0.54	0.45	0.33	0.34
UZAYBIMER	0.48	0.48	0.36	0.37
UZAYMER	0.46	0.40	0.35	0.35
TUR	0.49	0.49	0.38	0.36
Global	0.39	0.43	0.34	0.35

Figure 5 shows the yearly mean temporal variations of absorbing aerosol values for Türkiye's major observatories, Türkiye, and the global. When the graphs in Figure 5 are analyzed, it can be seen that all PAAI values increase between 1979 and 2005, decrease between 2005 and 2010, and remain relatively stable after 2010. The annual average PAAI values for Türkiye range from 0.30 to 0.60 (1982 and 2001) and from 0.28 to 0.55 for the world (1986 and 2005). However, it can be seen from the graphs that Türkiye's average PAAI values are above the global average values. The reason for this is that dust is frequently transported from the large deserts around Türkiye (African and Middle Eastern deserts). An analysis of the annual PAAI values of the observatories indicates that high values were observed in UZAYBIMER, COMUUO, IsUO, and TUG sites, respectively, while low PAAI values were observed in EUO and DAG sites. When the values of the observatories and Türkiye are analyzed from the figure, it can be seen that the DAG values are generally below and parallel to the values of Türkiye. Values at TUG, on the other hand, exhibited a more fluctuating change over the years and were mostly above the Türkiye average.

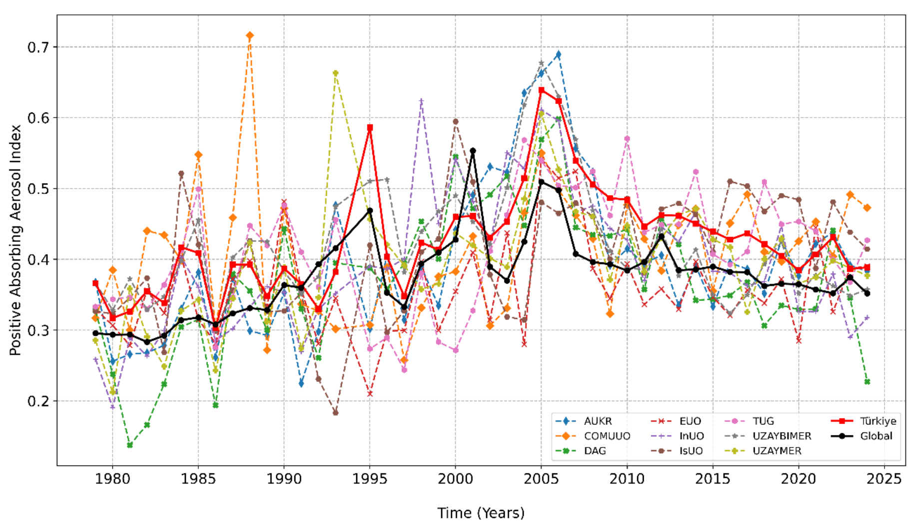

Figure 5 Yearly mean PAAI values for the observatories.

Seasonal decomposition is defined as the separation of time series data into trend, seasonal and residual components. Temporal data may depend on previous values, seasons and external factors. Figures 6 and 7 show the seasonal decomposition of monthly mean PAAI values for the observatories, Türkiye and Global. The graphs are ordered from top to bottom as original observation, trend, seasonal and residual components. A thorough examination of the PAAI values at DAG presented in the figure indicates the presence of a highly irregular structure within the DAG PAAI data. It appears that the level has remained relatively consistent since the 2000s. The present study has revealed an upward trend in the PAAI values at DAG between 1980 and 2005. Following 2005, a slight fluctuation is observed, with a more pronounced decrease evident after 2020. The seasonal component is quite distinct and exhibits a structure that repeats itself on an annual basis. The wave height is typically constant, exhibiting a consistent seasonal pattern on an annual basis. It is evident that the components under consideration are generally symmetrical and randomly distributed in the center (around zero). There are notable high deviations in some periods, especially in the 1990s and early 2010s. The DAG PAAI series has been observed to exhibit a distinct seasonal structure, characterized by an initial increase that extends until approximately 2005, following which a decline is initiated. The seasonal effects are constant and robust. It is possible to make similar evaluations of the values at DAG for other observatories, Türkiye and global PAAI values from Figures 6 and 7.

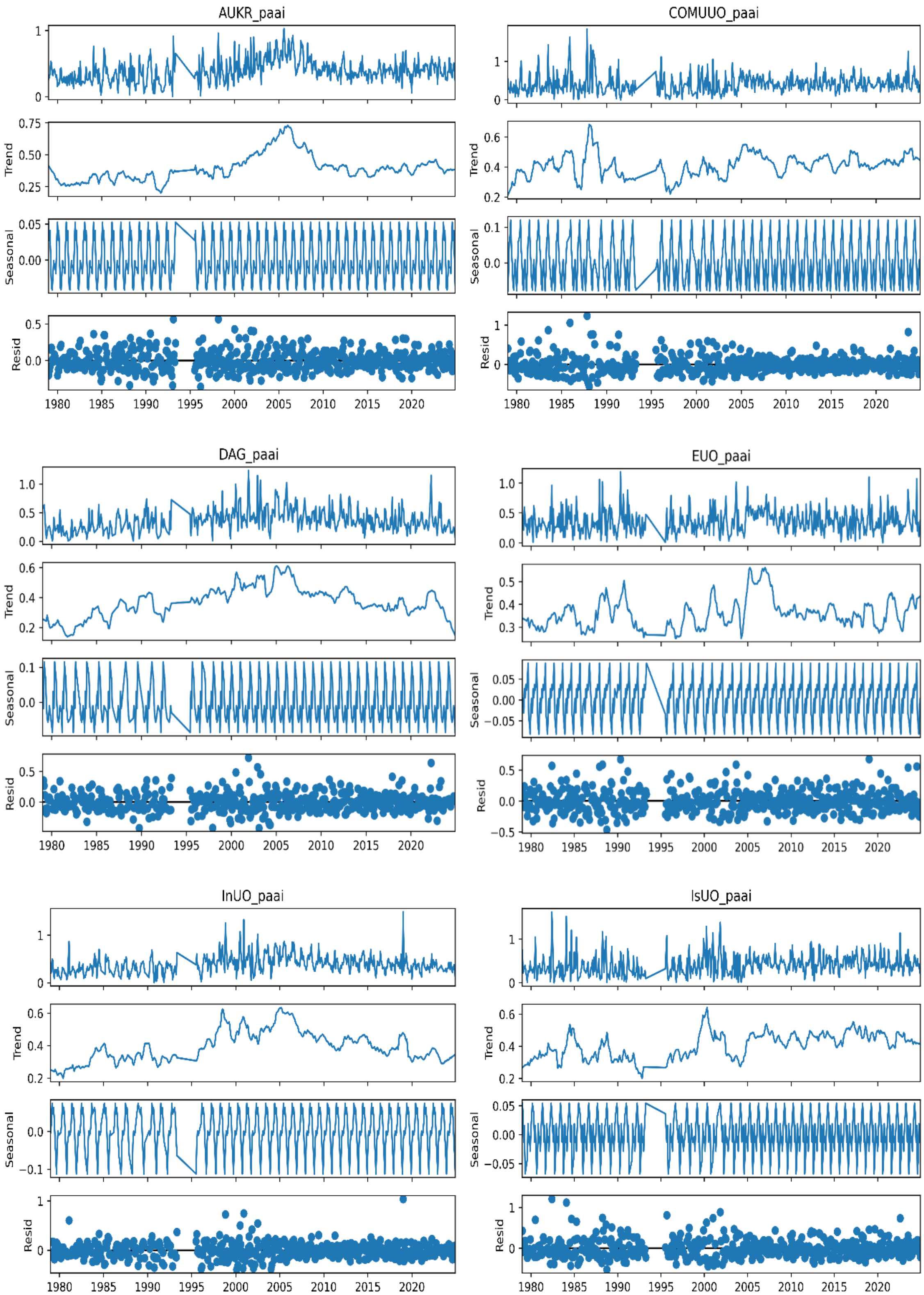

Figure 6 Seasonal decomposition of observatories -1

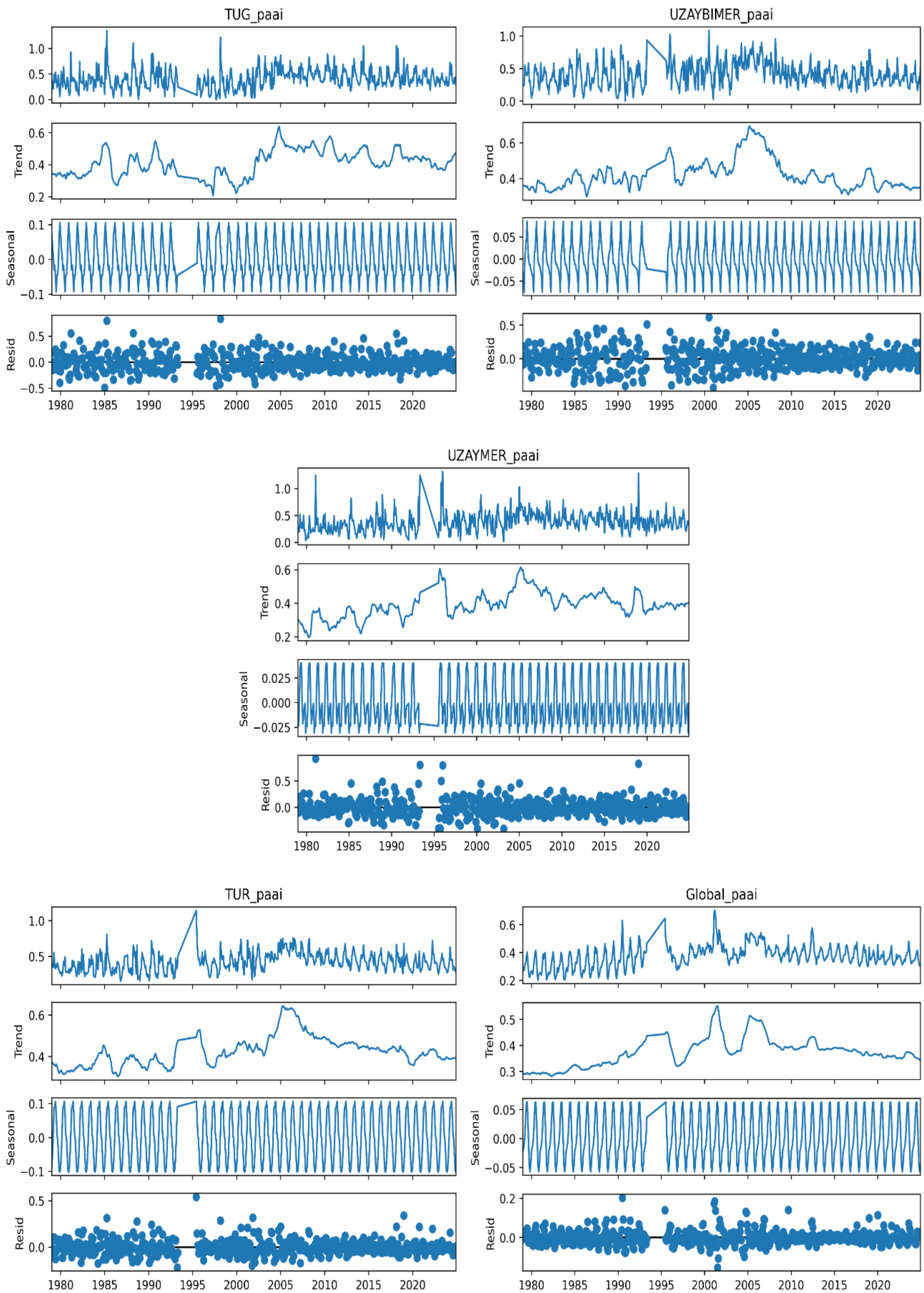

Figure 7 Seasonal decomposition of observatories -2

Conclusion

Türkiye and its major observatories are affected by dust transported from both local and distant sources. To determine the severity of this effect, we examine of absorbing aerosols for the ground-based astronomical observations in Türkiye by reviewing their spatial and temporal variability. The optimal conditions for ground-based astronomical observatories are the Atacama Desert in Chile, Hawaii, Namibia (where levels of PAAI are comparatively low), and the Canary Islands (where medium levels of PAAI occur, and occasional effects from Saharan dust may be experienced) and significant challenges include northern India, central Africa and eastern China for global scale. For the Türkiye scale, low PAAI values occur in high altitude areas, medium-level PAAI values (0.3 - 0.6) occur in the southern region of Central Anatolia, the eastern Mediterranean region, and the westernmost region of the Southeast and high PAAI (>0.6) values are observed in the region surrounding Şanlıurfa, Mardin, and the Syrian border. DAG site can be classified as very good, TUG and COMUUO as good, and EUO and IsUO as moderate in terms of PAAI. The global average PAAI value for 2024 is calculated as 0.34, which is lower than the 45-year long-term average of 0.38. However, the Türkiye average for 2024 is 0.39, which is nearly equivalent to the long-term global average. The long-term highest monthly aerosol values are generally observed in UZAYBİMER, COMUUO, IsUO and TUG sites, respectively. Conversely, the lowest aerosol values were observed in the EUO, and DAG areas. The long-term seasonal PAAI values for these sites indicate that high aerosol levels are observed in spring and summer seasons, while low aerosol levels are recorded in autumn and winter seasons. PAAI values increased between 1979 and 2005, decreased between 2005 and 2010, and remain relatively stable after 2010 for the all sites. PAAI values at DAG indicate the presence of a highly irregular structure. The present study has revealed an upward trend in the PAAI values at DAG between 1980 and 2005. Following 2005, a slight fluctuation is observed, with a more pronounced decrease evident after 2020. The seasonal component is quite distinct and exhibits a structure that repeats itself on an annual basis.

Hakem Değerlendirmesi: *Dış bağımsız.*
Yazar Katkıları: *Konsept – SA, FP, KK; Tasarım - SA, FP, KK; Denetim - SA, FP, KK ; Kaynaklar - SA; Malzemeler - SA, FP, KK; Veri Toplama ve/veya İşleme - SA, FP, KK; Analiz ve/veya Yorum - SA, FP, KK; Literatür Taraması - SA, FP, KK; Yazma - SA, FP, KK; Eleştirel İnceleme - SA, FP, KK; Diğer – SA, FP, KK*
Çıkar Çatışması: *Yazarlar, çıkar çatışması olmadığını beyan etmiştir.*
Finansal Destek: *Yazarlar bu çalışma için finansal destek almadıklarını beyan etmişlerdir.*
Peer-review*: Externally peer-reviewed.*
Author Contributions: *Concept – SA, FP, KK; Design – SA, FP, KK; Supervision – SA, FP, KK; Resources – SA; Materials – SA, FP, KK; Data Collection and/or Processing – SA, FP, KK; Analysis and/or Interpretation – SA, FP, KK; Literature Review – SA, FP, KK; Writing – SA, FP, KK; Critical Review – SA, FP, KK; Other – SA, FP, KK.*
Conflict of Interest: *The authors have no conflicts of interest to declare.*
Financial Disclosure: *The authors declared that this study has received no financial support.*

References

Aslanoğlu, S. Y., Proestakis, E., Gkikas, A., Güllü, G., & Amiridis, V. (2022). Dust climatology of Turkey as a part of the Eastern Mediterranean Basin via 9-year CALIPSO-derived product. *Atmosphere*, 13(5), 733. https://doi.org/10.3390/atmos13050733

Balarabe, M., Abdullah, K., Nawawi, M., & Khalil, A. E. (2016). Monthly temporal-spatial variability and estimation of absorbing aerosol index using ground-based meteorological data in Nigeria. *Atmospheric and Climate Sciences*, 6(03), 425. https://doi.org/10.4236/acs.2016.63035

Cavazzani, S., Ortolani, S., Bertolo, A., Binotto, R., Fiorentin, P., Carraro, G., & Zitelli, V. (2020). Satellite measurements of artificial light at night: Aerosol effects. *Monthly Notices of the Royal Astronomical Society*, 499(4), 5075–5089. https://doi.org/10.1093/mnras/staa3157

Gan, Y., Zhang, Z., Liu, F., Chen, Z., Guo, Q., Zhu, Z., & Ren, Y. (2024). Analysis of characteristics and changes in three-dimensional spatial and temporal distribution of aerosol types in Central Asia. *Science of The Total Environment*, 927, 172196. https://doi.org/10.1016/j.scitotenv.2024.172196

Holben, B. N., Eck, T. F., Slutsker, I. A., Tanre, D., Buis, J. P., Setzer, A., ... & Smirnov, A. (1998). AERONET—A federated instrument network and data archive for aerosol characterization. *Remote Sensing of Environment*, 66(1), 1-16. https://doi.org/10.1016/S0034-4257(98)00031-5

Isik, A. G., Aslanoğlu, S. Y., & Güllü, G. (2024). Long-term evaluation of aerosol optical properties in the Levantine region: A comparative analysis of AERONET and Aqua/MODIS. *Remote Sensing*, 16(14), 2651. https://doi.org/10.3390/rs16142651

Jackson, J. M., Liu, H., Laszlo, I., Kondragunta, S., Remer, L. A., Huang, J., & Huang, H. C. (2013). Suomi-NPP VIIRS aerosol algorithms and data products. *Journal of Geophysical Research: Atmospheres*, 118(22), 12-673. https://doi.org/10.1002/2013JD020449

Jiadan, D., Liqiao, T., Fang, C., Xiaobin, C., Xiaoling, C., Qiangqiang, X., & Xinghui, X. (2023). Spatio-temporal variations of aerosol optical depth over Ukraine under the Russia-Ukraine war. *Atmospheric Environment*, 314, 120114. https://doi.org/10.1016/j.atmosenv.2023.120114

Kocifaj, M., & Bará, S. (2020). Night-time monitoring of the aerosol content of the lower atmosphere by differential photometry of the anthropogenic skyglow. *Monthly Notices of the Royal Astronomical Society: Letters*, 500(1), L47–L51. https://doi.org/10.1093/mnrasl/slaa181

Kooreman, M. L., Stammes, P., Trees, V., Sneep, M., Tilstra, L. G., de Graaf, M., ... & Veefkind, J. P. (2020). Effects of clouds on the UV Absorbing Aerosol Index from TROPOMI. *Atmospheric Measurement Techniques Discussions*, 2020, 1-31. https://doi.org/10.5194/amt-13-6407-2020

Levy, R. C., 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(D13). https://doi.org/10.1029/2006JD007811

Liu, J., Ding, J., Li, L., Li, X., Zhang, Z., Ran, S., Ge, X., Zhang, J., Wang, J., 2020. Characteristics of aerosol optical depth over land types in central Asia. Science of the Total Environment 727, 138676. https://doi.org/10.1016/j.scitotenv.2020.138676

Mikhalev, A. V., Tashchilin, M. A., & Sakerin, S. M. (2019). Effect of atmospheric aerosol on ground-based airglow observations. *Atmospheric and Oceanic Optics*, 32, 410–415. https://doi.org/10.1134/S1024856019040109

Osgouei, P. E., & Kaya, Ş. (2023). A comprehensıve analysıs of the spatıo-temporal varıatıon of satellıte-based aerosol optıcal depth ın marmara regıon of turkıye durıng 2000–2021. *The Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 509-514. https://doi.org/10.5194/isprs-archives-XLVIII-M-1-2023-509-2023

Ozdemir, E., Tuygun, G. T., & Elbir, T. (2020). Application of aerosol classification methods based on AERONET version 3 product over eastern Mediterranean and Black Sea. *Atmospheric Pollution Research*, 11(12), 2226-2243. https://doi.org/10.1016/j.apr.2020.06.008

Remer, L. A., Kaufman, Y. J., Tanré, D., Mattoo, S., Chu, D. A., Martins, J. V., ... & Holben, B. N. (2005). The MODIS aerosol algorithm, products, and validation. *Journal of the Atmospheric Sciences*, 62(4), 947-973. https://doi.org/10.1175/JAS3385.1

Sánchez, S. F., Aceituno, J., Thiele, U., Pérez-Ramírez, D., & Alves, J. (2007). The night sky at the Calar Alto Observatory. *Publications of the Astronomical Society of the Pacific*, 119(860), 1186–1198. https://doi.org/10.1086/522378.

Shaylor, M., Brindley, H., & Sellar, A. (2022). An evaluation of two decades of aerosol optical depth retrievals from MODIS over Australia. *Remote Sensing*, 14(11), 2664. https://doi.org/10.3390/rs14112664

Tariq, S., Shahzad, H., Mehmood, U., & Haq, Z. U. (2023). Linear and wavelet analysis of aerosol optical depth (AOD) and prevailing meteorological factors during summer (2003–2016) over Turkey using Remote Sensing. *Air Quality, Atmosphere & Health*, 16(12), 2509-2528. https://doi.org/10.1007/s11869-023-01422-0

Tilstra, L. G., Tuinder, O. N., & Stammes, P. (2010, September). GOME-2 absorbing aerosol index: Statistical analysis, comparison to GOME-1 and impact of instrument degradation. *The 2010 EUMETSAT Meteorological Satellite Conference* (p. 57). Retrieved from https://www-cdn.eumetsat.int/files/2020-04/pdf_conf_p57_s4_12_tilstra_p.pdf

Tutsak, E., & Koçak, M. (2020). Optical and microphysical properties of the columnar Aerosol burden over the Eastern Mediterranean: Discrimination of Aerosol types. *Atmospheric Environment*, 229, 117463. https://doi.org/10.1016/j.atmosenv.2020.117463

Tuygun, G. T., & Elbir, T. (2020). Long-term temporal analysis of the columnar and surface aerosol relationship with planetary boundary layer height at a southern coastal site of Turkey. *Atmospheric Pollution Research*, 11(12), 2259-2269. https://doi.org/10.1016/j.apr.2020.09.008

Tuygun, G. T., & Elbir, T. (2023). Long-term spatiotemporal variation in atmospheric aerosol properties over Türkiye based on MERRA-2 reanalysis data: aerosol classification based on city type. *Environmental Science and Pollution Research*, 31(28), 40655-40668. https://doi.org/10.1007/s11356-023-27920-3

Tuygun, G. T., & Elbir, T. (2024). Comparative analysis of CAMS aerosol optical depth data and AERONET observations in the Eastern Mediterranean over 19 years. *Environmental Science and Pollution Research*, 31(18), 27069-27084. https://doi.org/10.1007/s11356-024-32950-6

Verma, S., Prakash, D., Soni, M., & Ram, K. (2019). Atmospheric aerosols monitoring: Ground and satellite-based instruments. In Advances in environmental monitoring and assessment. *IntechOpen*. https://doi.org/10.5772/intechopen.80489.

Yoshioka, M., Mahowald, N., Dufresne, J. L., & Luo, C. (2005). Simulation of absorbing aerosol indices for African dust. *Journal of Geophysical Research: Atmospheres*, 110(D18). https://doi.org/10.1029/2004JD005276

Zhang, H. H., Liu, X. W., Yuan, H. B., Zhao, H. B., Yao, J. S., Zhang, H. W., & Xiang, M. S. (2013). Atmospheric extinction coefficients and night sky brightness at the Xuyi Observation Station. *Research in Astronomy and Astrophysics*, 13(4), 490–502. https://doi.org/10.1088/1674-4527/13/4/010