Scientific and Social Research, 2025, Volume 7, Issue 1
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Spatiotemporal Distribution Characteristics of Global Coarse-Mode Aerosol Optical Depth from 2012 to 2021

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Abstract: Aerosols, as suspended solid and liquid particles in the atmosphere, play a significant role in global climate change and environmental quality. This study utilizes global coarse-mode aerosol optical depth (CAOD) data from 2012 to 2021, derived through a deep learning model, to comprehensively analyze the spatiotemporal distribution characteristics of coarse-mode aerosols. The findings reveal that global CAOD values exhibit a fluctuating downward trend during the study period, with a more pronounced decline in the Northern Hemisphere, likely due to regional variations in climate change, desertification, and human activities. Spatially, regions such as North Africa, the Middle East, and parts of Asia show higher CAOD values, associated with desert dust activity and anthropogenic emissions, whereas regions like South America, Australia, and Antarctica have lower CAOD values, attributed to their cleaner atmospheric conditions and minimal human activity. The complex CAOD variations in the mid-latitudes of the Northern Hemisphere are influenced by climatic conditions, topographical features, and the distribution of human activities. This study provides critical data for understanding the role of coarse-mode aerosols in global climate change and highlights the importance of considering geographical differences in aerosol distribution in climate change research. The study offers a scientific basis for formulating environmental policies and interventions. Future research will further explore the specific contributions of aerosol sources and their interaction mechanisms with climate change.

Keywords: Coarse mode aerosol; Spatial-temporal pattern; Global distribution; Trend analysis

1. Introduction

Aerosols, composed of suspended solid and liquid particles, vary significantly in space and time due to their short atmospheric lifespan and diverse sources [1]. Coarse-mode aerosols, originating from natural sources like desert dust and sea salt, and fine-mode aerosols, primarily from human activities, contribute to this complexity

[2]. Understanding the distribution of coarse-mode aerosols (CAOD) is critical for assessing their climate and environmental impacts. In recent years, advancements in satellite remote sensing have facilitated progress in monitoring and studying CAOD [3]. However, the limited data duration and high uncertainties of satellite products have constrained CAOD's applicability in climate research [4]. To address these challenges, Zhou Zang et al. proposed a novel spatiotemporal collaborative deep learning model (SCAM) for the retrieval of global land CAOD from 2001 to 2021 [5]. Unlike traditional deep learning models, SCAM accounts for the interaction of spatiotemporal features and simultaneously captures both linear and nonlinear relationships, significantly improving the accuracy and coverage of daily global CAOD.

This study aims to utilize CAOD data retrieved by the SCAM model to conduct an in-depth analysis of the long-term spatiotemporal distribution patterns of coarse-mode aerosols from 2012 to 2021. Through this analysis, this study seeks to enhance the understanding of the role of coarse-mode aerosols in global climate change and their potential impacts on the environment and human health.

2. Data

To systematically describe the spatiotemporal distribution patterns of global CAOD, this study utilized the global land coarse-mode Aerosol Optical Depth (CAOD) dataset, based on the SCAM (Semi-Continuous Aerosol Module) algorithm. The dataset, covering daily CAOD data from 2012 to 2021, is accessible at https://zenodo.org/records/7829679. This CAOD dataset provides a crucial foundation for analyzing the spatiotemporal characteristics of global coarse-mode aerosols. Due to its high sensitivity to coarse-mode aerosols, the dataset effectively captures the distribution characteristics of coarse aerosols and is significant for exploring the relationship between climate change and aerosols. The SCAM-derived global land CAOD dataset features a spatial resolution of 0.5° x 0.5° and a daily temporal resolution.

3. Results

3.1. CAOD Global temporal pattern

Figure 1a presents the annual average CAOD from 2012 to 2021. The CAOD reached its lowest points in 2014 and 2019, with peaks in 2012, 2016, and 2021. The minimum value (0.0806) occurred in 2019, while the maximum value (0.1003) was observed in 2012. Overall, global CAOD showed a fluctuating downward trend from 2012 to 2021. **Figure 1b** and **Figure 1c** display the annual average CAOD for the Northern and Southern Hemispheres, respectively, during the same period. The annual average AOD 550 ranged from 0.0934 to 0.1186 in the Northern Hemisphere and from 0.0421 to 0.0512 in the Southern Hemisphere, with the Northern Hemisphere significantly higher than the Southern Hemisphere. Additionally, linear regression analysis (dashed lines) was conducted in **Figure 1**. The linear regression equation is defined as:

$$\mathrm{CAOD}(x)=\mathrm{A}x+\mathrm{B}$$

In the equation, x represents the predictor (year), which corresponds to the sequence of years. A is the slope of the linear regression equation, and B is the intercept. Both the predictor (year) and the predicted value (CAOD) follow a t-distribution with 16 degrees of freedom, as well as an F-distribution with 1 degree of freedom in the numerator and 16 degrees of freedom in the denominator. The R-values for the linear regression equations for the global, Northern Hemisphere, and Southern Hemisphere were -0.57633, -0.60949, and -0.11125, respectively. The linear regression analysis revealed negative slopes for all three cases, indicating a clear downward trend in global CAOD (global: -0.00121/year, Northern Hemisphere: -0.00164/year, Southern Hemisphere: -0.00009/year), with a significance level greater than 95%.

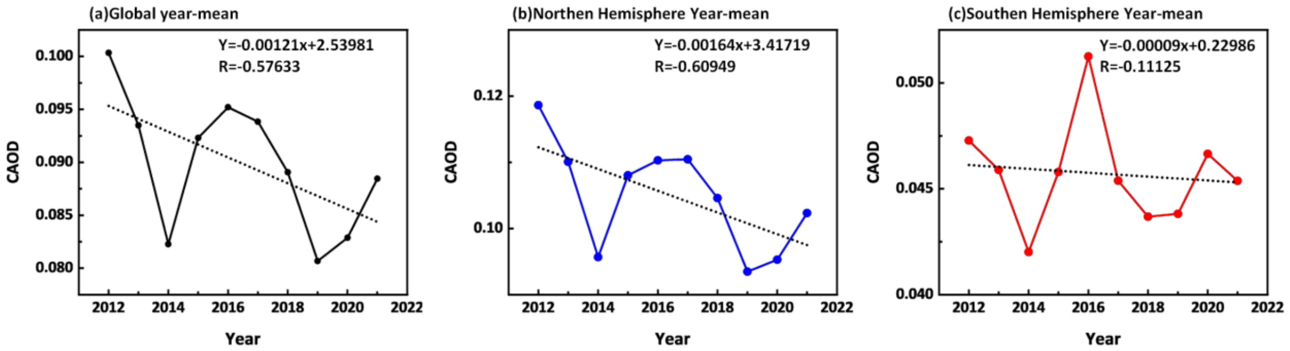

Figure 1. Annual average CAOD from 2012 to 2021 for (a) Global, (b) Northern Hemisphere, and (c) Southern Hemisphere

3.2. CAOD global latitude and longitude distribution

Figure 2 illustrates the global distribution of coarse-mode Aerosol Optical Depth (CAOD) across different latitudes. CAOD values are lower in the high latitudes of the Southern Hemisphere (-70° to -30°) due to minimal human activity and a pristine environment [6]. In the mid-latitudes (-20° to 20°), CAOD increases, influenced by human activities and natural sources like desert dust [7]. In the Northern Hemisphere (20° to 40°), CAOD values show complex variations, with lower median values (0.138 to 0.146) between 20° and 30°, and fluctuating values (0.075 to 0.056) between 30° and 40°, driven by diverse climates and human activity [8]. In the Western Hemisphere (-180° to -90°), CAOD remains low due to fewer human activities and natural sources [9]. Conversely, the Eastern Hemisphere (0° to 180°) shows higher CAOD, especially near the Sahara and Gobi Deserts, where strong winds elevate dust levels, particularly in spring and summer [10]. Overall, CAOD values exhibit a clear latitudinal dependency, ranging from low values in the Southern Hemisphere to complex variations in the mid-latitudes of the Northern Hemisphere. These findings provide crucial data for understanding the role of coarse-mode aerosols in global climate change. The longitudinal distribution characteristics also reflect the combined influence of natural and anthropogenic factors in different regions, offering key insights into the impact of coarse-mode aerosols on global climate dynamics.

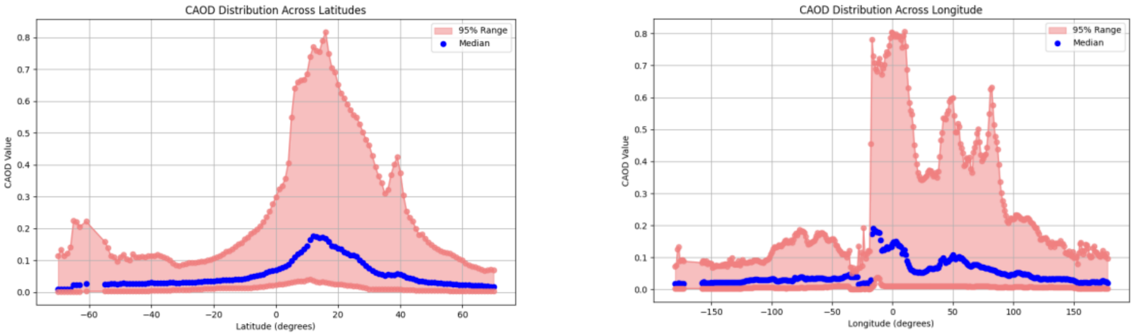

Figure 2. Mean CAOD values by latitude (A) and longitude (B)

3.3. CAOD global spatial pattern

Figure 3 shows the analysis of the spatial distribution of global coarse-mode Aerosol Optical Depth (CAOD) from 2012 to 2021. High CAOD values are observed in North Africa, the Middle East, and parts of Asia, driven by desert dust from regions like the Sahara and the Arabian Desert, and amplified by industrialization and urbanization [11]. In contrast, South America, Australia, and Antarctica exhibit low CAOD due to minimal human activity and cleaner atmospheric conditions [12]. Mid-latitude regions in the Northern Hemisphere show varied CAOD levels, influenced by diverse climates, topography, and human activities. Industrialized areas in Europe and North America see elevated CAOD, while Asia's values are affected by monsoonal variations [13]. This CAOD map highlights the global distribution of coarse aerosols, offering insights into their impact on climate, air quality, and health, and emphasizes the need for targeted environmental policies.

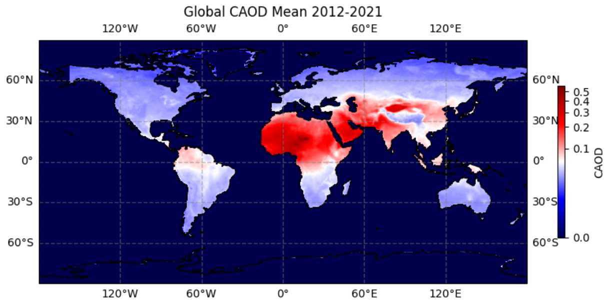

Figure 3. Global distribution of CAOD

4. Conclusion

This study analyzes global coarse-mode Aerosol Optical Depth (CAOD) data from 2012 to 2021, revealing its distribution characteristics and trends across the globe. The results indicate that global CAOD values showed a fluctuating downward trend during the period from 2012 to 2021, with a more significant decline in the Northern Hemisphere. This phenomenon may be linked to global climate change, desertification levels, and regional differences in human activities. In terms of spatial distribution, CAOD values are abnormally high in North Africa, the Middle East, and parts of Asia, which can be attributed to the widespread desert areas, strong wind effects, and rapid industrialization in these regions. Desert dust activities and anthropogenic aerosol emissions in these areas jointly contribute to the increase in CAOD values. In contrast, regions such as South America, Australia, and Antarctica show relatively low CAOD values, likely due to cleaner atmospheric conditions and lower levels of human activity. Additionally, the CAOD values in mid-latitude regions of the Northern Hemisphere exhibit complex variations influenced by diverse climate conditions, topographical features, and the distribution of human activities. In some parts of Europe and North America, higher CAOD values are observed due to elevated industrialization and traffic emissions. In Asia, the CAOD values are influenced by the monsoon climate, showing distinct seasonal variations.

The findings of this study not only provide visual evidence for understanding the global distribution of coarse-mode aerosols but also offer valuable insights into evaluating the impact of aerosols on regional climate, air quality, and human health. These results emphasize the importance of considering geographical differences in aerosol distribution in global climate change research, and they provide scientific support for the formulation of targeted environmental policies and interventions. Future research could further explore the specific contributions of aerosol sources in different regions and the interaction mechanisms between aerosols and climate change.

Disclosure statement

The author declares no conflict of interest.

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