environmental sciences proceedings

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Proceeding Paper

A Global Climatology (2005–2021) of Sea-Salt Aerosols Using MODIS and OMI Satellite Data †

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† Presented at the 16th International Conference on Meteorology, Climatology and Atmospheric Physics—COMECAP 2023, Athens, Greece, 25–29 September 2023.

Abstract: A global climatology of sea-salt aerosols for the 17-year period 2005–2021 is produced with a satellite algorithm that uses input data of spectral aerosol optical depth (AOD) and single scattering albedo (SSA) at 388 nm, taken from MODIS-Aqua Collection 6.1 and OMI-Aura Satellite databases, respectively. The results show that the maximum frequency of occurrence of sea-salt aerosols is observed over the Southern Tropical Pacific and Indian oceans, with values up to 60 and 70 days per year, respectively, while on a global mean basis, the sea-salt aerosols are observed with a decreasing frequency from 2005 to 2021.

Keywords: sea-salt aerosol; satellite observations; aerosol optical depth; single scattering albedo; absolute frequency of occurrence

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Citation: Elli, M.; Nikos, H.; Maria, G.; Korras-Carraca, M.-B.; Stamatis, M. A Global Climatology (2005–2021) of Sea-Salt Aerosols Using MODIS and OMI Satellite Data. *Environ. Sci. Proc.* **2023**, *26*, 43. https://doi.org/10.3390/environsciproc2023026043

Academic Editors: Konstantinos Moustris and Panagiotis Nastos

Published: 24 August 2023

1. Introduction

Sea-salt aerosols are strongly scattering coarse aerosols produced by natural processes over oceans, which are important to the physics and chemistry of the marine terrestrial atmosphere. More specifically, the main factor that contributes to their production is wind, which causes the generation of waves, thus leading to their injection into the overlying atmospheric levels and subsequent horizontal transport. Indeed, most of them can be transported by atmospheric circulation to short distances from their sources, but smaller particles can be transported to farther distances being detected not only over oceanic, but also over adjacent continental areas, in association with their longer lifetime [1]. Sea-salt aerosols are hygroscopic and can absorb water, acting as efficient cloud condensation nuclei (CCN), influencing the physical and optical properties of clouds, such as reflectivity, lifetime and extent [2]. Because of the significant climatic effects of sea-salt aerosols, it is important to gain knowledge about their spatiotemporal distribution, especially at large spatial and temporal scales. This can only be achieved by applying satellite-based techniques, which offer complete global coverage.

In the present study, sea-salt aerosols are detected globally during the 17-year period 2005–2021 using a satellite algorithm relying on key aerosol optical properties, characteristic of their size and absorptivity.

2. Data and Methodology

The algorithm operates on a daily basis and at spatial coverage of $1^\circ \times 1^\circ$ and uses as input data the aerosol optical depth (AOD), in seven wavelengths over oceans (470, 550, 650, 860, 1240, 1630, 2130 nm) and three wavelengths over land (470, 550, 660 nm), from the

MODIS-Aqua Collection 6.1 and aerosol single scattering albedo (SSA) at 388 nm from the OMI-Aura satellite databases, respectively. OMI-OMAEROe satellite SSA data were used over oceans and OMI-OMAERUV data over land. The separation between land and ocean was made using globally distributed surface-type data from the International Satellite Cloud Climatology Project (ISCCP)–H Basic Series. The algorithm first calculates the Angstrom Exponent (AE) at 470–660 nm over land and 470–2130 nm over ocean using AOD spectral data from the MODIS satellite database. Then, the algorithm applies appropriate thresholds to the AE (AE $\geq$ 0.4) and SSA (0.99 $\leq$ SSA $\leq$ 1.0) to determine the presence or absence of sea-salt aerosols. The algorithm runs every day of each year and estimates the absolute frequency of occurrence of sea-salt aerosols on an annual basis both at the pixel level and on a global mean basis. These annual values have been averaged over each year of the period 2005–2021 to yield a climatology of the absolute frequency of occurrence of sea-salt. The inter-annual variability and changes from 2005 to 2021 are also examined.

3. Results

The operation of the satellite algorithm largely depends on the availability of all of its input data. It is important to have the algorithm operating on an about equal rate of day/year over the globe in order to ensure the representativeness of the inter-annual variability of the frequency of occurrence of sea-salt aerosols as well as their geographical variability. Thus, in Figure 1, the 17-year (2005–2021) mean annual climatological values of the days/year for which the satellite algorithm operated are presented. It appears that the highest values are observed over the Indian, Pacific and Atlantic Oceans, where the algorithm operated on average for 120–170 days per year. On the other hand, the minimum values are observed in the Southern Ocean, as well in the northern Atlantic and Pacific oceans where the algorithm operated for about 30–50 days per year. Zero frequencies exist over the Arctic and Antarctic areas (deepest blue-colored areas).

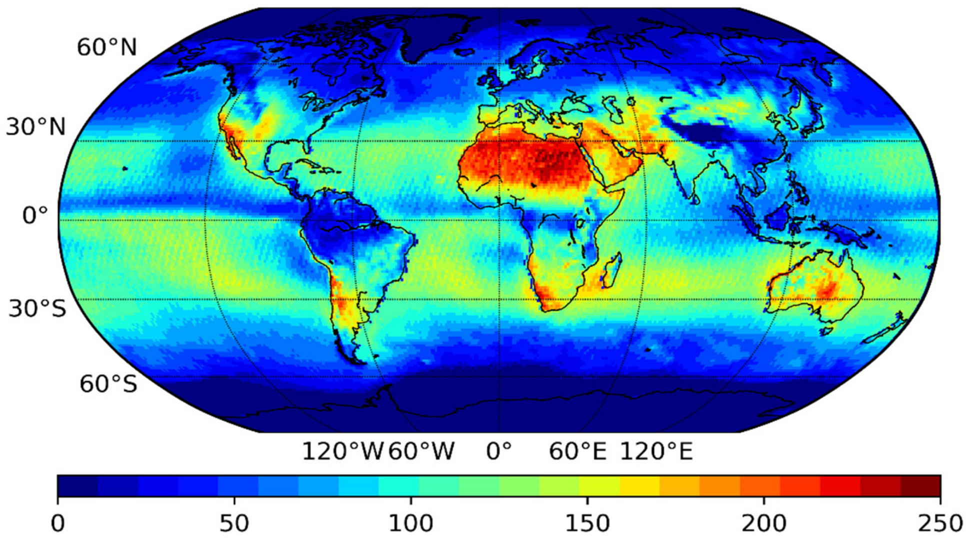

Figure 1. Number of days for which the satellite algorithm operated in each year. The results are averaged over the 17-year study period (2005–2021).

The algorithm estimated the global distribution of the absolute frequency of occurrence of sea-salt aerosols (in days/year) for each year of the study period (2005–2021). Then the mean annual climatological distribution was computed by averaging the annual results, and the results are given in Figure 2. The white-shaded cells indicate areas where the algorithm did not work on any day (zero values/deep blue colors in Figure 1) due to the lack of satellite data. The areas for which the algorithm operated but did not identify any sea-salt aerosols are indicated with the deep blue colors in Figure 2. The map demonstrates that sea-salt aerosols never predominate the atmospheric column over continental regions (deep blue colors), whereas they do so on average for more than 30 days per year over oceanic regions (cyan, greenish, yellowish and reddish colors). More specifically, the Indian Ocean and the South tropical and sub-tropical Pacific Ocean, especially west of South America, have the highest frequencies, with up to 60–70 days per year. The frequency of occurrence decreases to 50–60 days/year in the South Pacific Ocean, especially west of South America (10°–30° S) and east of Australia. Lower frequencies (30–40 days/year) are found along the tropical North Pacific Ocean (up to 10° N). Over the Southern Ocean, marine sea-salt aerosols are observed on several days per year, but on a frequency (20–35 days/year) that is significantly lower than in the afore-mentioned oceanic regions. Even smaller frequencies are found in the North Atlantic Ocean, where sea-salt aerosols are observed on 10–20 days/year. Yet, frequencies up to 30 days/year are observed over the Caribbean Sea and north of Brazil.

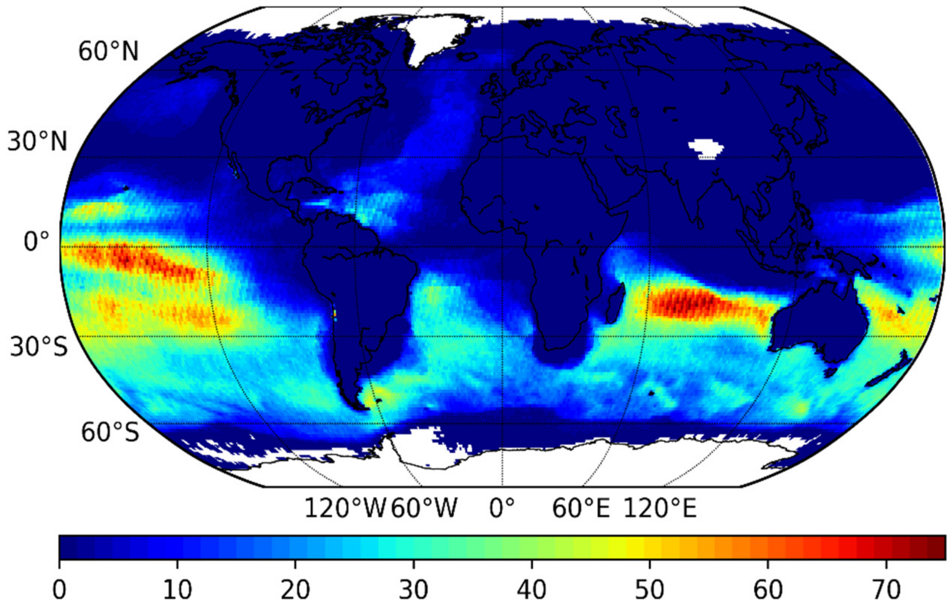

Figure 2. Global distribution of the absolute frequency of occurrence of sea-salt aerosols (in days/year) averaged over the period 2005–2021. White areas are those for which the algorithm did not work due to lack of input data.

In Figure 3, the year-to-year variation of the annual global mean frequency of occurrence of sea-salt aerosols is shown. The values given in this diagram correspond to a spatiotemporal frequency, calculated as the sum of each cell's absolute frequency, in each year. It appears that sea-salt aerosols are observed annually over 215,000–754,000 grid cells all over the globe, or over 525,000 grid cells on average, thus showing a relatively wide range of year-to-year variability (equal to about 100% of the 17-year mean frequency of occurrence). Also, according to this figure, the absolute frequency of occurrence of sea-salt aerosols significantly decreased during the study period 2005–2021, showing a reduction rate equal to 84.7%, which is statistically significant at the 95% level of significance.

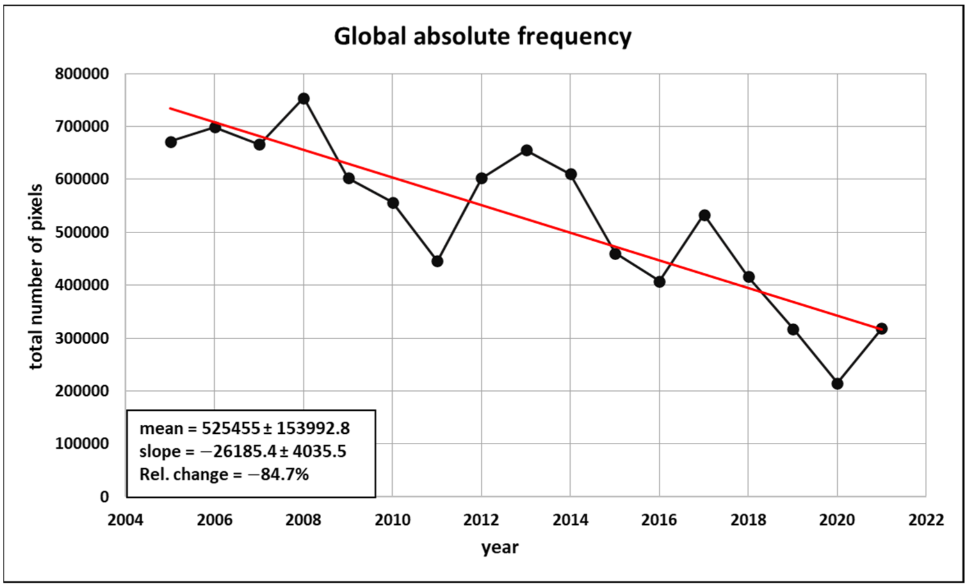

Figure 3. Interannual variation of the frequency of occurrence of sea-salt aerosols (in total number of grid cells of the planet where sea-salt aerosols were detected by the satellite algorithm). The applied linear regression to the time series and the computed linear trend and change of the absolute frequency of occurrence are also given.

4. Conclusions

In the present study, a satellite algorithm was used to detect sea-salt aerosols on a global scale during the period 2005–2021. The algorithm operated on a daily basis at a spatial coverage of $1° \times 1°$ in each year and estimated the annual absolute frequency of occurrence of sea-salt aerosols. The annual results were averaged to obtain the climatological mean (for the period 2005–2021) global distributions of sea-salt aerosols as well as the interannual variation and change in the absolute frequency of occurrence on a global basis. According to the algorithm results, sea-salt aerosols are mainly observed in the Southern Hemisphere and more over oceanic regions than continental areas. Larger frequencies are observed over the Indian Ocean, the tropical and sub-tropical Pacific Ocean, and less in the North Atlantic and Southern Oceans, with the highest values being observed over the Indian and South Pacific Oceans, especially west of South America on 60–70 days/year. The lowest frequencies are found in the North Atlantic Ocean with 10–20 days/year. On a global mean basis, the absolute frequency of occurrence of sea-salt aerosols significantly decreased during the study period (reduction rate of 84.7%) indicating a decrease of planetary albedo, which deserves to be assessed in a future work.

Author Contributions: Conceptualization, H.N.; methodology, H.N. and G.M.; software, H.N. and G.M.; validation, M.E., G.M. and M.-B.K.-C.; formal analysis, M.E. and G.M.; investigation, M.E.; resources, H.N.; data curation, G.M. and M.S.; writing—original draft preparation, M.E.; writing—review and editing, H.N., G.M., M.-B.K.-C. and M.S.; visualization, M.E. and G.M.; supervision, H.N. and G.M.; project administration, H.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Marios-Bruno Korras-Carraca was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "2nd Call for H.F.R.I. Research Projects to support Post-Doctoral Researchers" (project acronym: ATLANTAS, project no. 544).

Conflicts of Interest: The authors declare no conflict of interest.

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