Exploring Seasonal and Monthly Variations in Columnar Aerosol Optical Properties over the Sultanate of Oman

Baiju Dayanandan[1]*, Ahmed Al Harrasi[1], Pawan Gupta[2], Tom Eck[2], Alexander Smirnov[2], Brent N. Holben[2], Vinoj[3], Ajay[4], Nirmal[1], Mohammed Safi Al Kalbani[5] & Humaid Al Badi[6]

[1]Natural and Medical Sciences Research Centre, University of Nizwa, Oman

[2]Goddard Space Flight Center, NASA, Greenbelt, MD 20771, USA

[3]Indian Institute of Technology Bhubaneswar, India

[4]Atmospheric Chemistry Observations & Modelling, NSF, National Centre for Atmospheric Research (NCAR), USA

[5]Oman Environment Authority, [6]Oman Civil Aviation Authority

Abstract

This study presents the first analysis of aerosol optical characteristics and radiative forcing over Nizwa, a remote site located on the northeastern side of the Sultanate of Oman, by utilizing ground-based AERONET observations during the year 2023. The aerosol optical depth (AOD) shows a significant variation throughout this period, with a maximum in the summer (0.51 ± 0.19) followed by autumn (0.34±0.11), spring (0.24±0.08) and a minimum in the winter (0.15± 0.06). The angstrom exponent (AE) remains below 1 throughout the year, with a maximum in winter (0.89±0.32) and a minimum in summer (0.34±0.14), indicating the abundance of coarse mode particles. The volume size distribution shows the domination of coarse-mode particles in every season, and the aerosol characteristics are mainly associated with the changes in coarse-mode particles. The spectral dependence of single scattering albedo (SSA) over the region shows higher values in summer, suggesting the presence of dust particles during this season. Throughout the entire study period, aerosol radiative forcing values at the top of the atmosphere (TOA) averaged at -17.64 Wm^{-2}, while surface values were recorded at -44.59 Wm^{-2}, resulting in an atmospheric forcing of 26.95 Wm^{-2} and heating rate of 0.75 K/day. The concentration-weighted trajectory (CWT) analysis indicates significant transport of aerosols from the arid regions of the horn of Africa contributing largely to the coarse mode aerosols and atmospheric radiative forcing (ATM) for the study period.

Why is this study?

Climate Impact: Aerosols influence the Earth's climate system by scattering and absorbing sunlight, affecting temperature patterns and weather conditions.

Air Quality: Aerosols, especially those with high pollutant concentrations, impact air quality and human health, contributing to respiratory issues.

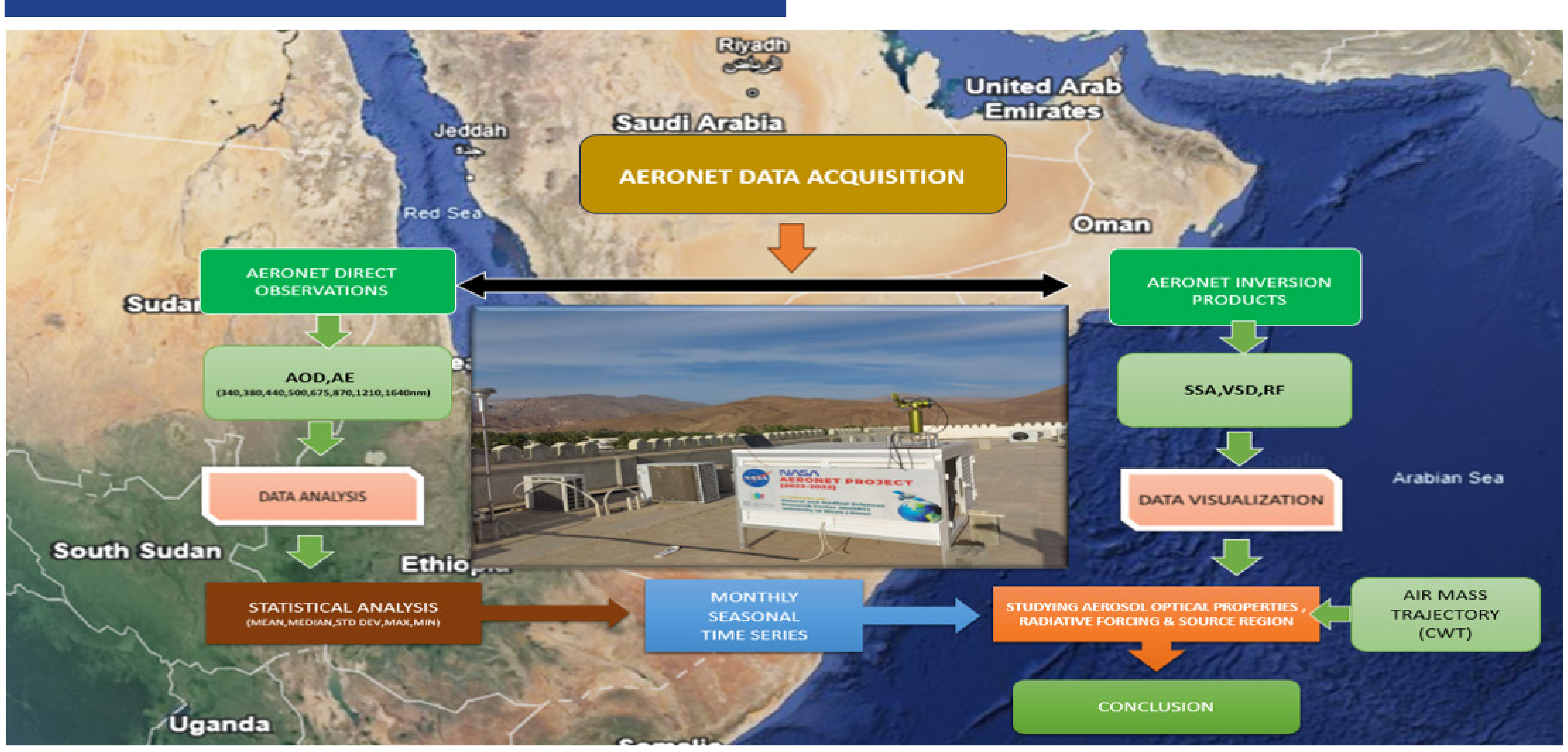
Environmental Processes: Aerosols play a role in processes like cloud formation and precipitation, influencing atmospheric and hydrological systems.

Global and Regional Impacts: Aerosol distribution varies globally and regionally, with concentrations influenced by natural and human factors. Studying aerosol climatology helps understand regional variations and their impacts.

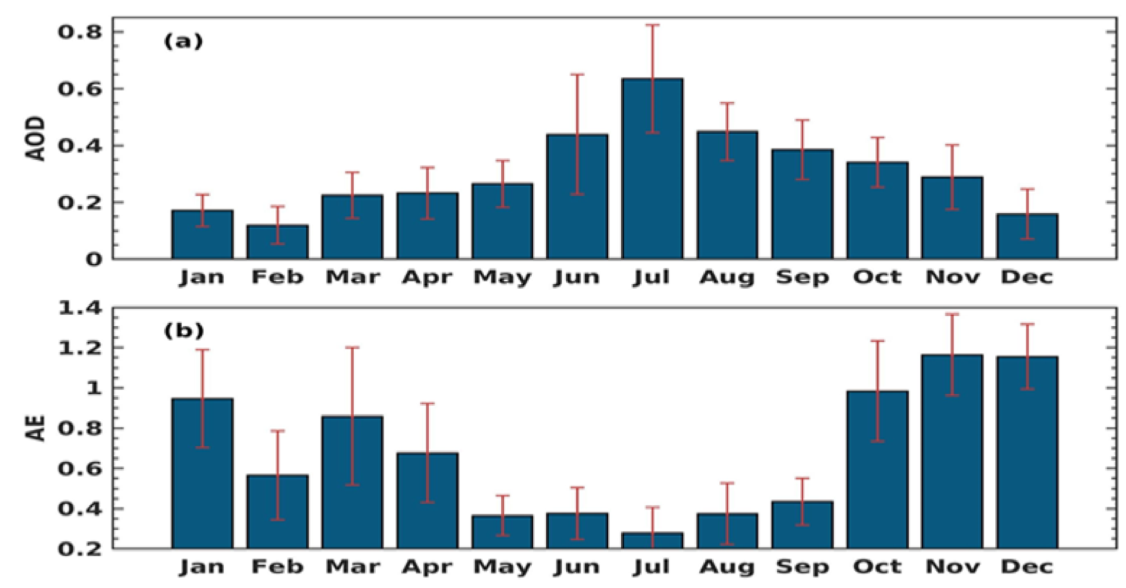
Climate Change Mitigation: Certain aerosols, like black carbon, contribute to warming. Understanding aerosol sources aids in developing strategies to mitigate their impact on climate change.

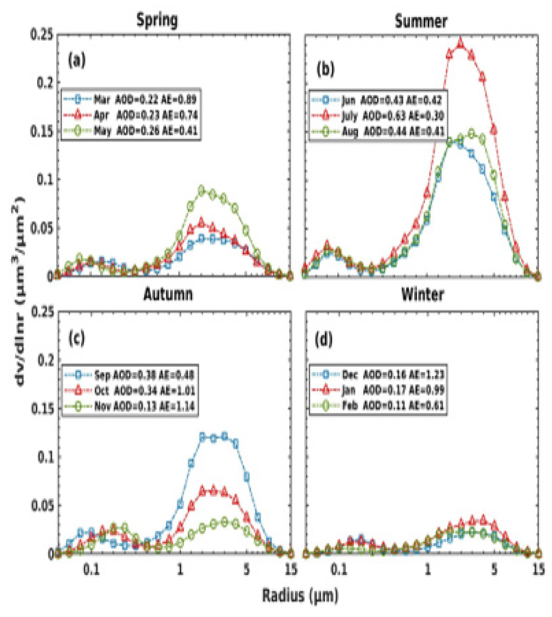
Satellite and Remote Sensing: Aerosols can be monitored using remote sensing technologies. Studying aerosol climatology enhances the accuracy of satellite data for climate modeling, weather forecasting and environmental monitoring.

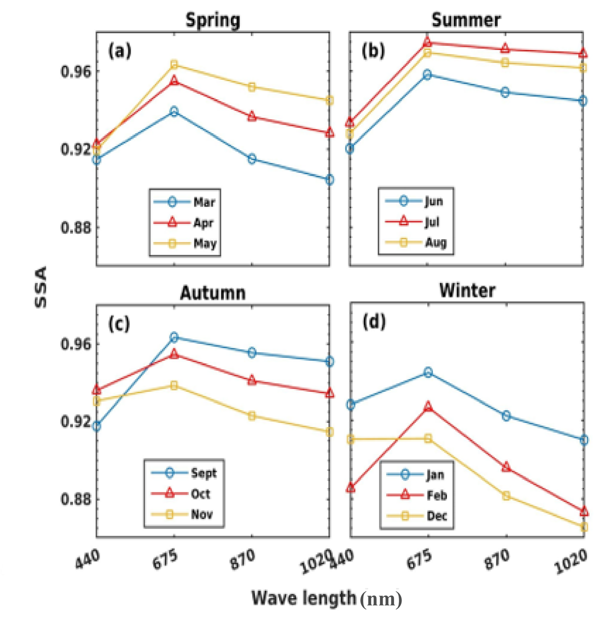
Methods

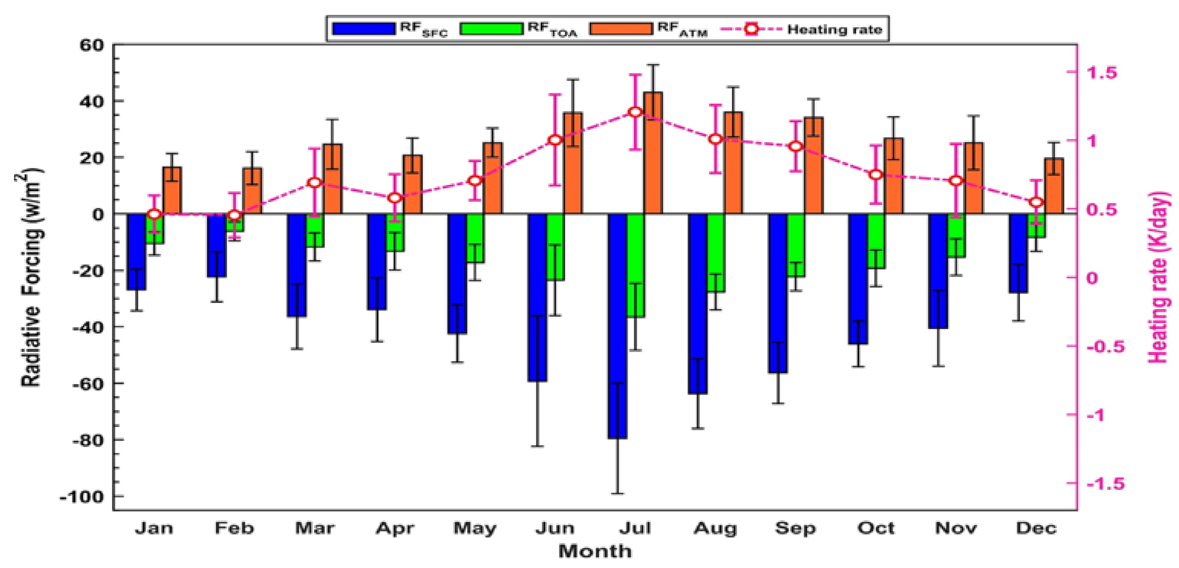


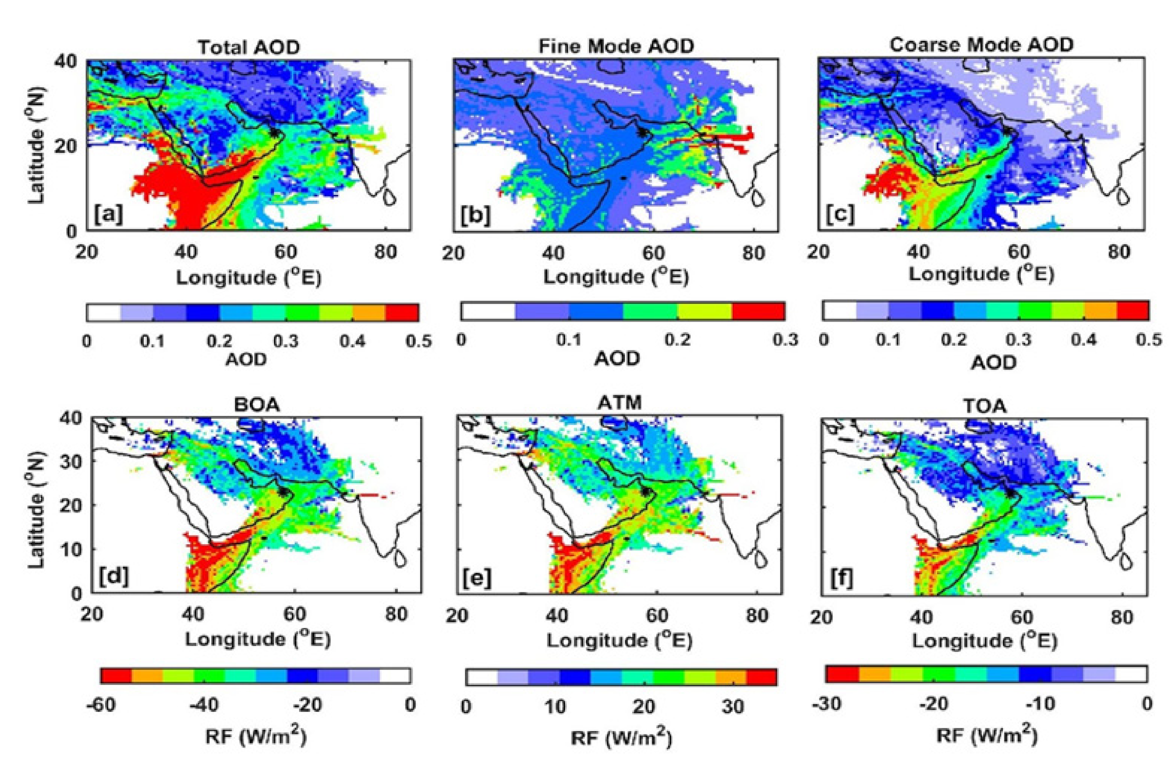
Results











Conclusions

1. Aerosol optical depth & Angstrom exponent :

Significant intra-annual variability in AOD was observed over Nizwa in 2023. The highest AOD values were recorded during the summer season (0.51±0.19), followed by autumn (0.34±0.11), spring (0.24±0.08) and winter (0.15±0.06). This trend is slightly different from the seasonal aerosol pattern typically observed in the Arabian Peninsula. In Nizwa during 2023, autumn tends to exhibit higher AOD values, while spring shows lower AOD values compared to the seasonal AOD values observed across the Arabian Peninsula in previous studies.

The AE exhibits an inverse trend compared to the AOD, with higher values observed during winter (0.89 ± 0.20), followed by autumn (0.86 ± 0.19), spring (0.63 ± 0.23) and summer (0.34 ± 0.14).

The analysis of AE and AOD indicates a significant presence of coarse mode particles in summer, with a subsequent decrease in their presence through autumn, spring and winter. The higher daily mean values of AE observed during the autumn, spring and winter seasons suggest the relative significance of fine-mode particles on certain days in this season.

2. Single scattering albedo:

Monthly averaged single scattering albedo (SSA) and spectral variability revealing significant seasonal changes. The SSA was found to increase in the wavelength range of 440–675 nm in the majority of the season. In summer the SSA shows spectral patterns similar to dust aerosol. In winter SSA is lower than in the other three seasons and showed a sharp spectral decrease indicating the reduction in dust aerosols and showing the significance of the fine mode particles. The average spectral dependence in Nizwa shows a slight decreasing trend after 675 nm, indicating the difference in aerosol properties over Nizwa in comparison with other regions in the Arabian Peninsula.

3. Volume size distribution:

Aerosol volume size distributions show the dominance of coarse mode particles in all seasons, and variations in the concentration of coarse mode aerosols are found to be the primary cause of the variation in the optical properties of the aerosol in Nizwa, consistent with previous studies at other stations in the Arabian Peninsula.

4. Radiative forcing and heating rate:

The aerosol radiative forcing is highly variable. At the surface, the radiative forcing has higher negative values (-17.64 Wm^{-2}) than at the top (-44.59 Wm^{-2}) of the atmosphere. The total atmosphere demonstrated a positive radiative forcing of 26.95 Wm^{-2}, indicating aerosol-induced warming in the atmosphere of Nizwa. The resulting heating rate is calculated, yielding the following seasonal values: during Summer, the rate is 1.07±0.28 K/day; in Autumn, it is 0.80±0.22 K/day; in Spring, it is 0.66±0.19 K/day; and in Winter, it is 0.48±0.15 K/day.

5. Aerosol sources and its effect on radiative forcing:

CWT analysis reveals that the horn of Africa and the southern region of the Arabian Peninsula are the potential sources of dust particles in Nizwa. Notably, significant fine-mode aerosols are transported to Nizwa from western India and the Arabian Sea region. Aerosols from the horn of Africa have a significant impact on radiative forcing above Nizwa, while contributions from the Arabian Sea and the northwest region of the Arabian Peninsula also impact radiative forcing in this region.

References

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