ASSESSING THE PERFORMANCE OF ALL-SKY IMAGERS IN ESTIMATING AEROSOL OPTICAL DEPTH IN SOLAR RESOURCE STUDIES: THE CASES OF GREECE AND QATAR

Summary

This study evaluates the capability of All-Sky Imagers (ASIs) to estimate Aerosol Optical Depth (AOD) by leveraging machine learning (ML) techniques and radiometric sky information. The research analyzes data from Greece and expands the application to Qatar region. The model utilizes RGB channel radiances and the Red-to-Blue Ratio (RBR) from the ASI's circumsolar region as primary inputs. While results for Greece show high correlation with AERONET ground-truth data, the study explores the transferability of these models to the desert environment of Qatar, where preliminary data suggests higher variances due to coarse dust particles. The findings aim to establish ASIs as low-cost, high-temporal-resolution supplements to sun photometer networks.

Keywords: All-Sky Imager, Aerosol Optical Depth, Machine Learning, Solar Resource, Greece, Qatar

Field of application for the findings: Solar resource assessment, atmospheric monitoring, and high-frequency solar forecasting for PV/CSP plants

Addressed audience: Solar Resource assessment specialists, Remote Sensing engineers, data scientists

1. Introduction

Aerosol Optical Depth (AOD) is a critical parameter for quantifying atmospheric aerosol loading, influencing both climate forcing and the available solar resource for energy production. While Sun Photometers (e.g., CIMEL CE318) provide high-precision spectral AOD, their spatial coverage is limited and they lack the continuous hemispherical monitoring provided by All-Sky Imagers (ASIs). This paper investigates whether a supervised machine learning approach trained on European aerosol conditions (Greece) can be adapted to the more extreme, dust-dominated conditions of the Middle East (Qatar). This comparison is vital for developing universal ASI-based AOD retrieval algorithms that can function across different aerosol regimes (maritime/urban vs. desert).

2. Methodology and Data

2.1. Instrumentation and site description

The study utilizes two primary locations:

- Patras/Athens, Greece: Representing a Mediterranean climate with mixed aerosol types (urban, maritime, and seasonal Saharan dust). The setup includes a Mobotix ASI and a collocated AERONET sun photometer.
- Doha, Qatar: A desert environment characterized by high AOD values and a dominance of coarse-mode dust particles. Due to the limited current availability of long-term image-photometer pairs in Qatar, this site is treated as a "preliminary validation" case. In upcoming paper, preliminary results will be presented by this site, too.

2.2. Feature extraction and ML model

Taking ASI image and geometrical calibration (transformation mapping each pixel coordinate (x, y) from the sensor plane to a discrete spherical coordinate pair: the zenith angle [0°, 90°] and the azimuth angle [0°, 360º]) plus solar current position as granted, we extract features from the "Circumsolar" and "Zenith" regions:

- Mean RGB Values: Calculated for a X x Y area around the sun.
- R/B and R/G Ratios: Higher Red-to-Blue ratios typically indicate higher dust concentrations.
- Solar Saturation Area: The number of overexposed pixels near the solar disk, which correlates strongly with forward scattering by large dust particles [2]. This measurement will be performed for all images of our DB, being captured in the same exposure time, for consistency and uniformity purposes.

In order to depict the significance of SSA, two cases from Athens' ASI with different AOD and almost identical solar geometries are represented in Figure 1. The increased solar disk in Figure 1b explains that increases in SSA are reflected in AOD increases (from 0.12 to 0.42). In particular, a higher SSA corresponds to a higher aerosol burden within the atmosphere, according to the Mie theory [1].

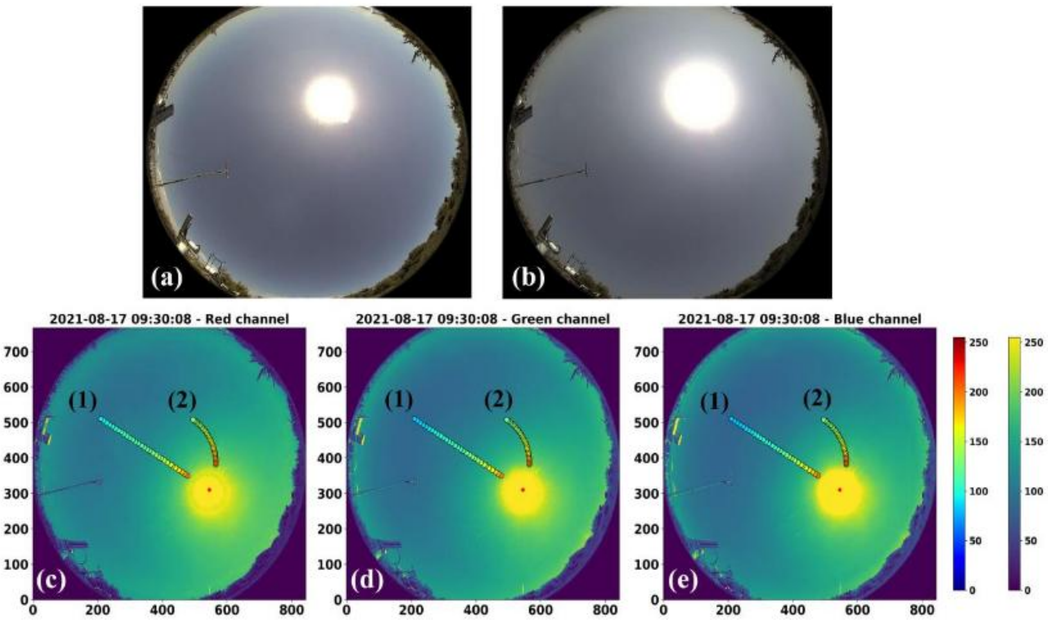

Fig. 1: Using Two all-sky imager (ASI) images with similar solar zenith angle (SZA) and different aerosol loads. The three heatmap images illustrate the 60 selected pixels in (c) red, (d) green, and (e) blue color scale. Both color bars indicate the intensity of the image color. The different color bars are applied to easily distinguish the selected pixels on the graph.

We implement a Machine Learning strategy based on the synergy of ASI image features and AERONET reference data. The image processing involves:

- ROI Selection: Extraction of the Principal Plane and the circumsolar region (angles 3°–10° from the solar disk).
- Color Analysis: Retrieval of the R, G, and B radiances.
- The Red-to-Blue Ratio (RBR), used as a proxy for aerosol scattering, as higher AOD typically correlates with an increase in the RBR due to the wavelength dependency of Mie scattering.
- Mapping algorithm: Following Logothetis et al. method [3], we employ a Random Forest (RF) and a Multilayer Perceptron (MLP) to map these RGB features to the target AOD at 500nm.

3. Final and preliminary results

3.1. Performance in Greece

Validation against AERONET data in Greece confirms the robustness of the ML model. The predicted AOD follows the reference values closely, with a Root Mean Square Error (RMSE) below 0.05. The model effectively captures the diurnal variation of aerosols, which is often missed by the lower temporal frequency of standard satellite products.

Tab 1. Statistical metrics for AOD at the three wavelengths for site in Greece.

Variable	MBE (rMBE)	RMSE (rRMSE)	R
AOD_{440nm}	−0.0012 (−0.51%)	0.056 (23.1%)	0.93
AOD_{500nm}	0.000069 (0.033%)	0.066 (32.4%)	0.89
AOD_{675nm}	−0.0011 (−0.71%)	0.053 (33.9%)	0.92

3.2. Preliminary findings in Qatar

Initial results from the Qatar dataset reveal higher absolute errors compared to the Greek case. This is attributed mostly to the dominance of dust, leading to high RBR values that occasionally saturate the model trained on Mediterranean data.

In Figure 2, the difference in measured SSA is related to low versus high measured AOD.

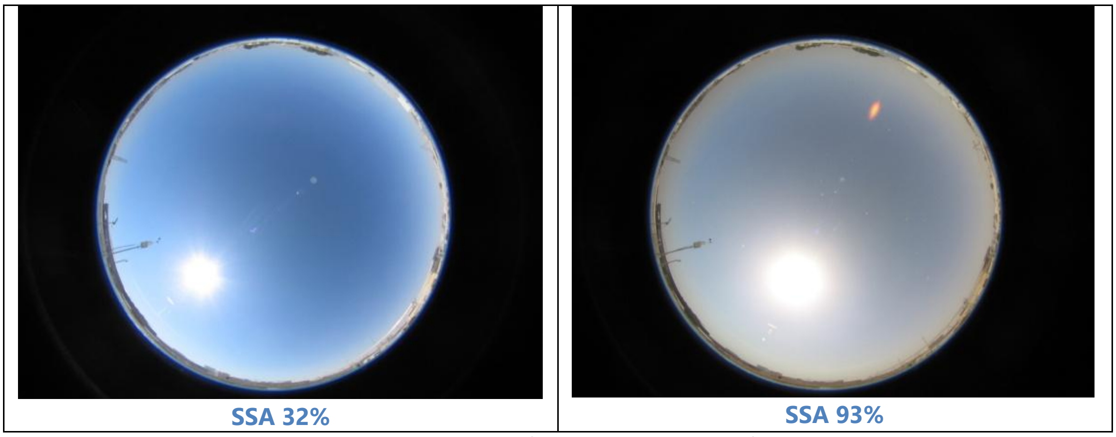

Fig. 2: The SSA percentages stand from low to high value of AOD gradually.

4. References

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