COST short-term scientific mission report

Near Real-time comparison of night-time aerosol optical depth (AOD) from Skynet and AERONET systems

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Duration: 04-14 February 2023

Action number: CA21119

Introduction

During our previous short-term scientific mission, which took place from 2nd July to 6th July 2023, our primary focus was on the implementation of an algorithm that could retrieve Aerosol Optical Depth (AOD) during night-time in different European Skynet Radiometer (ESR) network sites. We put in a lot of effort and managed to successfully implement the algorithm on the server, which led us to retrieve AOD measurements during night-time for the tested site.

Our algorithm is based on the methodology described by (Uchiyama et al., 2019) for retrieving lunar AOD. Proper calibration is crucial for successful retrieval. However, the changing phase of the moon, low signal, and non-uniform lunar surface pose significant challenges. The constantly changing phase of the moon results in fewer observations and makes it difficult to perform a calibration by using the Standard Langley plot technique. To account for the non-uniform lunar surface, we use the lunar model ROLO (Kieffer & Stone, 2005), which has an error of around 10% (A. Barreto et al., 2013). Uchiyama et al. (2019) found a way to optimize the calibration calculation method to overcome these challenges. They presented a method to calculate the calibration constant without relying on the Standard Langley plot for any lunar POM. We utilized his technique to acquire the calibration constant for the POM installed at the University of Sapienza. We then proceeded to modify the current Sunrad algorithm (Estellés et al., 2012) which determines AOD through direct solar irradiance. These enhancements now allow the algorithm to retrieve AOD measurements even during night-time hours.

After a successful test run, we were able to retrieve the nighttime AOD from Prede instrument. To verify the accuracy of the retrieved AOD, we compared it with the AERONET night-time AOD. Unfortunately, we did not have a working CIMEL and POM at the same location, which would have been ideal. Therefore, we assumed that since the distance between the available AERONET (Lunar) sites at Tor Vergata is roughly 20 km from University of Sapienza (Lunar PREDE), the day-time AOD at both sites would be comparable (RMSD of AERONET direct sun data at the two site is (0.034, 0.028, 0.024, 0.018, 0.015, 0.014) for wavelengths (340, 440, 500, 675, 870, 1020 nm) respectively). We found that the comparison of cloud-screened data was very good in our preliminary analysis. Our results were very promising and indicated that our algorithm was able to effectively retrieve AOD measurements during night-time.

Following the successful retrieval of night-time AOD during the last STSM, we decided to enhance our network by incorporating additional sites and upgrading our retrieval system to offer two types of data products in the current STSM. The first product, L2A, is produced using the current solar calibration value that is available within our server (kind of monthly pre-calibration only). Subsequently, when we obtain the next calibration value for the month, we reprocess the data while accounting for the calibration drift caused by instrument degradation. This reprocessed product is referred to as L2.

To showcase the precision and reliability of our retrieval algorithm, we conducted a comparative analysis between AERONET night-time AOD and night-time AOD obtained using our algorithm at Tor Vergata. The purpose of this analysis was to demonstrate that our algorithm can accurately retrieve the same data as AERONET. By comparing the two sets of data, we were able to confirm that our algorithm is capable of producing reliable and consistent measurements of atmospheric aerosols, even at night.

We have achieved all the objectives which include:

1. Successful implementation of automatic inversion of nocturnal data from all the lunar POM operatives in the ESR web page.
2. Automatic update of solar/lunar monthly calibration value of POMs using ISDC outputs.
3. Comparison of night-time AOD for collocated AERONET and PREDE at daily level.
4. Night-time data made available to download at the ESR website.

Instrumentation

To retrieve night-time aerosol properties, we created two FORTRAN modules from the versions available from SUNRAD: dsform and dsproc. These modules have similarities to the original Sunrad pack and work to create a data triplet within a minute using the dsform module. This triplet is then processed by the dsproc module to retrieve the aerosol properties, while also performing cloud screening akin to the method in (Smirnov et al., 2000).

Dsform module

Within Sunrad, the Dsform module generates measurement triplets in under a minute. While raw observation data is typically grouped into triplets in the original Sunrad model, minor processing is added to night-time data before triplet creation:

$$V(\lambda_0) = \frac{CA_{ROLO}}{\pi}\Omega_M \frac{V_{S0}(\lambda_0)}{R_S^2}\frac{1}{R_m^2}\exp(-m(\theta)\tau(\lambda_0))T_{gas}(\lambda_0,\theta)$$

(1)

Where:

$F_C . C' = C$

A_{ROLO} is ROLO reflectance

C' is the constant of proportionality for error in the ROLO model (Barreto et al., 2016) and F_c is the smoothing constant for ROLO reflectance.

R_s is the distance between sun and moon in astronomical units,

R_m is the distance between moon and the observer (normalized by 384400 km),

$V_{S0}(\lambda_0)$ is the calibration value obtained from direct sun measurements,

T_{gas} is the transmittance due to gas absorption.

m is the air mass

τ is the aerosol optical depth.

$$V(\lambda_0) = \frac{V_{S0}(\lambda_0)}{R_S^2} \exp(-m(\theta)\tau(\lambda_0))T_{gas}(\lambda_0, \theta)$$

(2)

where R_s is the distance between sun and earth in astronomical units,

Equation 1 shows the expression of the observed signal for a lunar POM (Uchiyama et al., 2019). Equation 2 shows the expression of the observed signal for a solar POM.

Arranging the equation 1, we can write it in the following form:

$$\frac{V(\lambda_0)\pi R_S^2 R_m^2}{\Omega_M C A_{ROLO}} = V_{S0}(\lambda_0)\exp(-m(\theta)\tau(\lambda_0))T_{gas}(\lambda_0, \theta)$$

(3)

$$V'(\lambda_0) = V_{S0}(\lambda_0) \exp(-m(\theta)\tau(\lambda_0))T_{gas}(\lambda_0, \theta)$$

(4)

$$V'(\lambda_0) = \frac{V(\lambda_0)\pi R_S^2 R_m^2}{\Omega_M C A_{ROLO}}$$

(5)

Equation 2 and 4 are similar. R_s term is missing in equation 4 but it is already included on the left side.
In dsform module, triplets of V' are created. Later they are used by dsproc module to retrieve the aerosol properties. Since we have adopted the modules from the Sunrad, we want to make least modification in the algorithm. To ensure this we rearranged the equation 1 and made it similar to the equation 2.

Dsproc module

This module is also a part of Sunrad. The function of this module is 1) to retrieve the aerosol properties using the solar calibration, 2) to perform the cloud screening using strategy similar to Smirnov et al. (2000). After the processing, two types of outputs are provided: cloud screened and not cloud screened.

Since, we are using the modules of Sunrad to process night-time data with required modifications. We named the package as Moonrad. Similar to Sunrad, it includes dsform and dsproc module to process the night-time data.

Types of data products

1) Level 2A- This data product is generated on the daily basis. To generate level 2A data products, we use the available calibration.

2) Level 2- It is generated once in a month. After creating level 2A data products, raw data is stored. Once we get the new calibration value for the month, whole raw data is reprocessed and we get Level 2 data products.

Sites

Currently, there are two sites in the ESR network that operate the lunar POM:

1) University of Sapienza, Rome, Italy (41.9° (41.9si° (; 83 m) - This site is situated in the centre of Rome. It is located 25 km east of the Tyrrhenian Sea. It is an urban site which is exposed to the urban emissions, by semi-rural particulates. Occasionally, it gets affected by desert dust due to advections from Sahara (Campanelli et al., 2022).

2) Tor Vergata, Rome, Italy (41.84° N, 12.65° E; 117 m.) – This site is situated around 20 km far away from Rome. It is surrounded by relatively cleaner environment as compared to the University of Sapienza.

Strategy to generate the data products.

Level 2A

1. Create the file name of the available raw data.
2. Add the header line to raw data if it is missing.
3. Generate the ROLO file for the raw data.
4. Run the algorithm to generate the level 2A data products.
5. Download the level 2A data from ISDC (data format is .nc)
6. Convert the nc files into ASCII.
7. Create a file where data is merged for everyday (for both Sun data and the Moon data).
8. Plot the merged data to get a continuous plot of day-night AOD.

Level 2

1. Download the calibration value from the ISDC.
2. Update the calibration value in the input file.

3. Compare the old calibration value and new calibration value. If the calibration values are same, no processing takes place. Only if the calibration values are different, we proceed to the next step.
4. Create the file name of the available raw data.
5. Add the header line to raw data if it is missing.
6. Generate the ROLO file for the raw data. ROLO files can be generated only for one month. If the calibration value is not available for more than one month, we accumulate two months of data. In this scenario, we process the data for one month at a time.
7. Run the Moonrad to generate the level 2 data products.
8. Download the level 2A data from ISDC (data format is .nc)
9. Convert the nc files into ASCII.
10. Create a file where data is merged for everyday (for both Sun data and the Moon data).
11. Plot the merged data to get a continuous plot of day-night AOD. In the Processing of both Level 2 and Level 2A, both cloud screened and non-cloud screened data is generated. The formats of the data produced are ".map, .opt, .esr"

Results

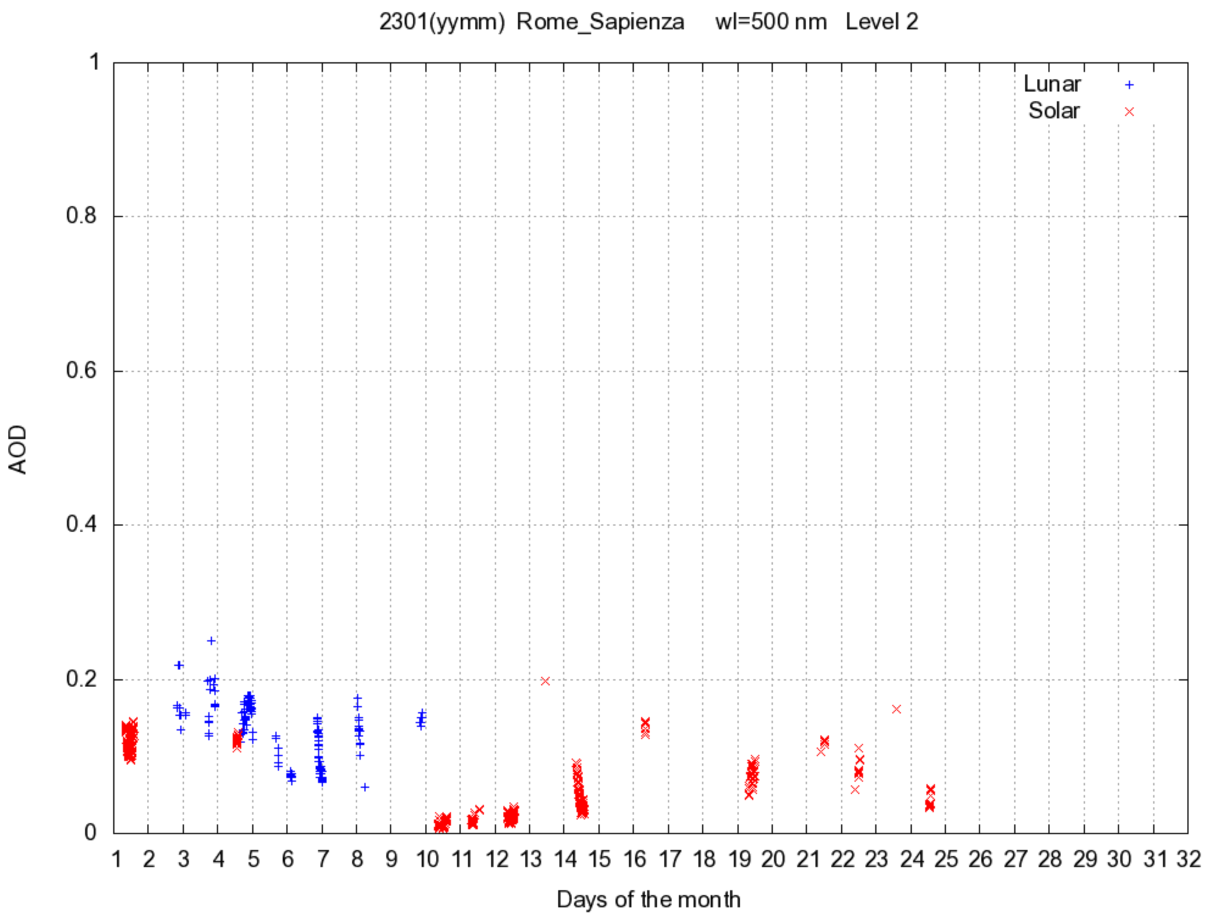

Figure 1 Time series of daytime and night-time AOD at 500 nm at University of Sapienza, Rome, Italy during January 2021 using PREDE data.

Figures 1 and 2 present time series plots of AOD at the 500nm channel at the University of Sapienza and Tor Vergata, respectively. These plots show that the AOD at night-time is consistent with the AOD during daytime when they are consecutive, indicating that our algorithm is functioning normally and is capable of calculating AOD during night-time as well.

Moreover, the most significant point that these plots highlight is the usefulness of this dataset. In Figure 1, we can observe that AOD is not available during the daytime from January 3rd to January 9th, which is likely due to cloudy weather during the winter season. However, we have AOD data during night-time during the same period, which is consistent with the AOD at the site. This helps us to maintain the continuity of the data at the site, and even at higher altitudes, AOD can be calculated using radiometers and the gaps in the data can be filled.

Similarly, Figure 2 demonstrates the consistency of the retrieval process, as the AOD during night-time agrees with the AOD during daytime.

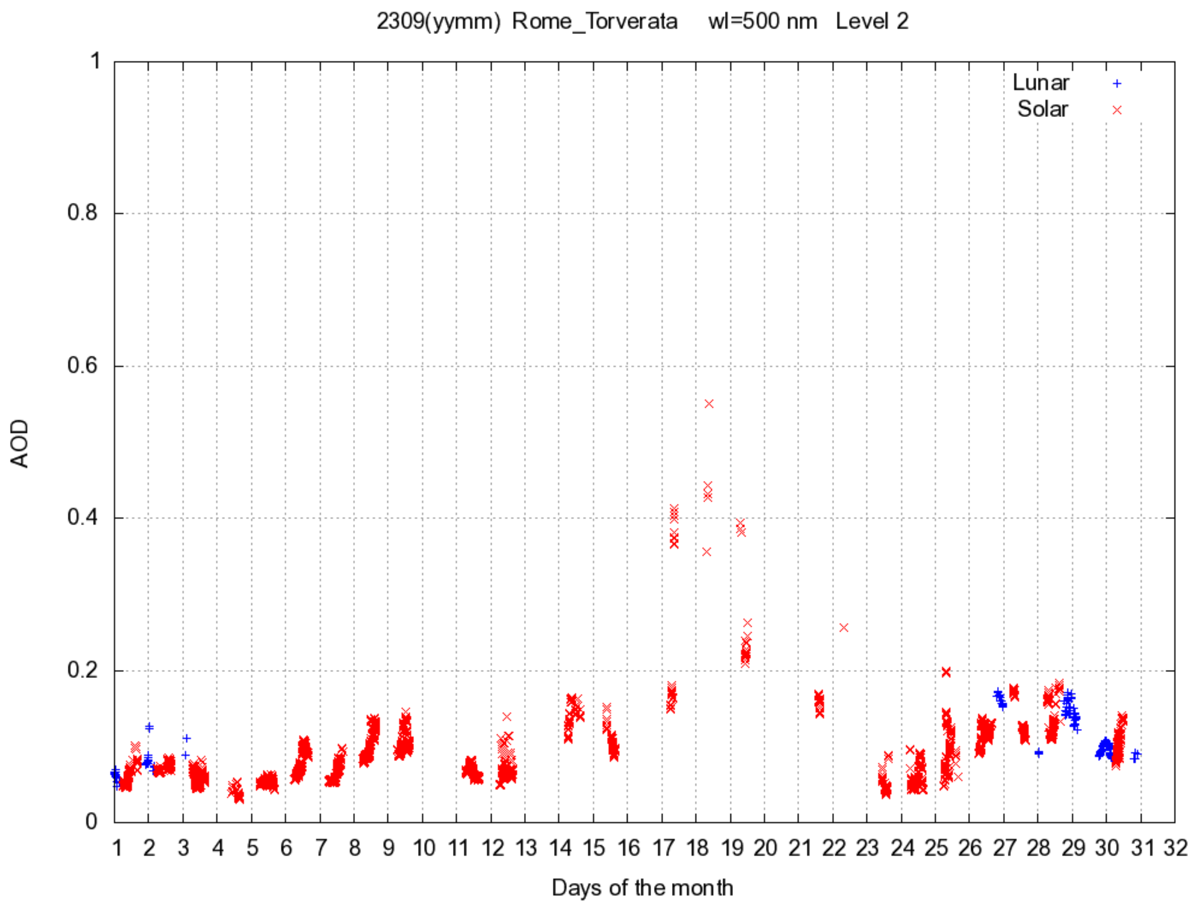

Figure 2 Time series of daytime and night-time AOD at 500 nm at Tor Vergata, Rome, Italy during January 2021

Comparison between AERONET and SKYNET at Tor Vergata

Data

Level 2 cloud free data is taken during the period of July 2023 to February 2024. Further, the data within 30 seconds of the measurement time of AERONET measurement is considered. This strategy is followed to compare the simultaneous measurements. Although we use to consider this limit to be 10 seconds, due to unavailability of the data, in this case we had to increase the limit to 30 seconds.

Results

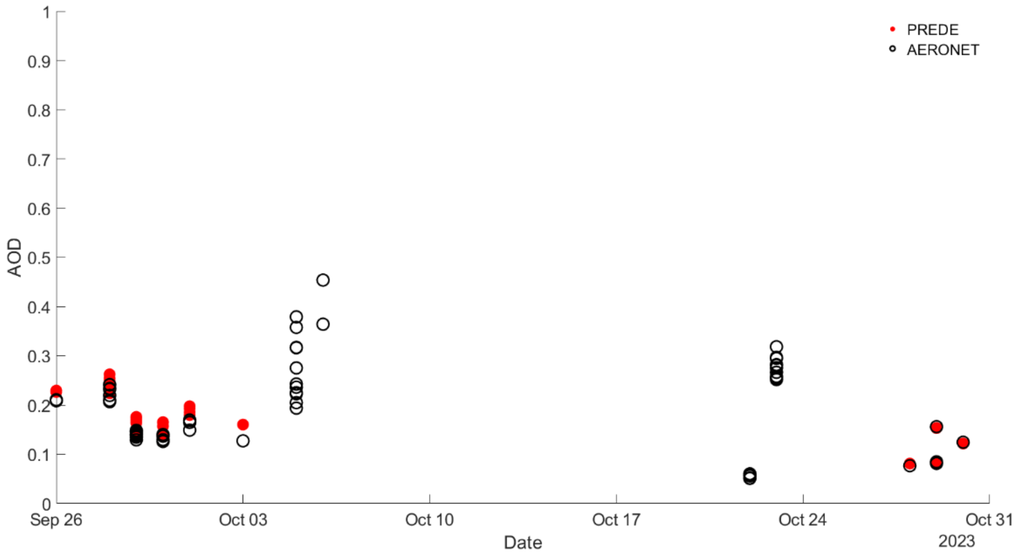

Figure 3 Comparison of AOD at 500 nm between AERONET and PREDE at Tor Vergata during July 2023 to February 2024

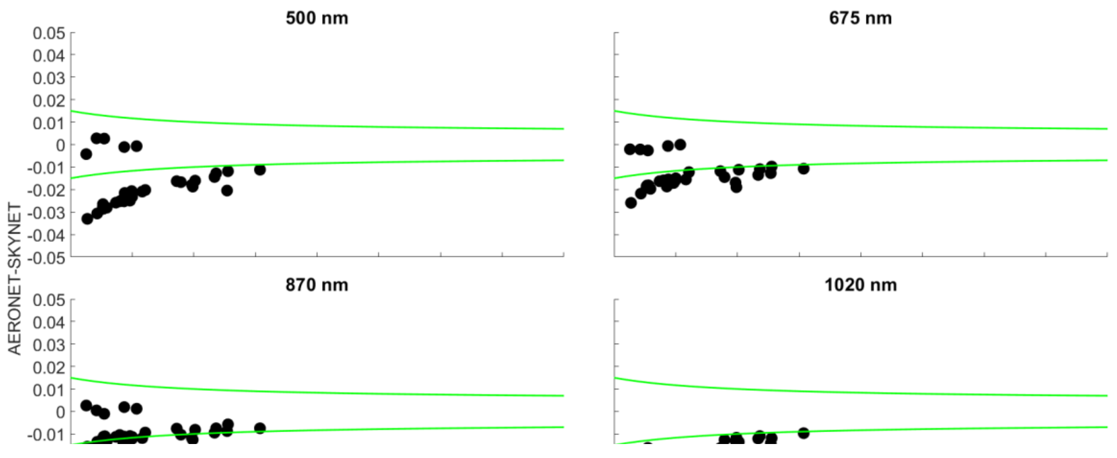

Figure 4 Scatter plot showing the points respect to the WMO limits (green lines) at Tor Vergata.

We performed two types of analysis: 1) Timeseries plot to see the consistence of the PREDE data with the AERONET data on daily basis. 2) WMO plots are made to check the quality of the data.

Figure 3 is the timeseries plot of AOD at 500 nm. In this plot, we see that PREDE data is aligned with the CIMEL data. We have less data points than AERONET. It can be due to stringent cloud screening criteria. Occasionally (not shown here), we observed abnormal AOD (>1) associated with PREDE, this was not observed with AERONET data. It could be maybe due to cloud screening. We are still using the cloud screening criteria developed for Sunrad which was primarily created for direct sun data. Due to time limitation during the STSM, we did not work on the adaptation of the cloud screening algorithm. In the future studies, this will be our primary focus.

Figure 4 is the scatter plot showing the WMO limits. Except for 875 nm, the values do not lie completely within the WMO lines at other channels (500 nm, 675 nm, 1020 nm). One of the reasons could be the unavailability of simultaneous measurements. 30 seconds is a big-time interval and atmospheric conditions can change during this interval. In the past study presented in EAC 2023 (Kumar et al., 2023), we analysed the data of Quatram campaign at University of Sapienza, Rome, during the MAPP project, using 10 seconds time interval, and we got very good results, with almost all the points were inside the WMO limits. Therefore, more research needs to be done for a better establishment of differences.

Table 1 Mean, STD and RMSD of the AOD at common channels.

	500 nm	675 nm	870 nm	1020 nm
Mean	0.200	0.150	0.123	0.1057
STD	0.010	0.006	0.005	0.009
RMSD	0.004	0.003	0.002	0.004

Table 1 shows the Mean, STD and RMSD of the AOD comparison for the common channels at Tor Vergata. Here, we see that the RMSD values are very small, within the nominal uncertainty. It indicates the AOD calculation by AERONET and the PREDE are in good agreement.

Conclusion

All the objectives of this STSM are achieved. We implemented an automated system at two operating sites. The system updates the calibration value every month from the ISDC website. We also made simultaneous daytime- night-time AOD plots for both the sites which shows the continuity of the data during daytime and night-time. It highlights the importance and utility of night-time AOD. Finally, the comparison of night-time AOD at Tor Vergata between AERONET and PREDE revealed, that both AERONET and PREDE are consistent, although more work needs to be done for a proper validation of the new method applied to Prede instruments.

Future Work

- Improvement of cloud screening algorithm- We observed that there were some abnormal values of AOD. We still use the same cloud screening which is used in Sunrad algorithm. In-depth study is required in future to improve or optimize the cloud screening method on lunar measurements.
- In the present study, we implemented the lunar AOD retrieval algorithm in two sites only (University of Sapienza and Tor Vergata). We plan to implement the algorithm in more sites in the future, so an analysis of site dependencies can be performed.
- In future, we shall do a study to validate the Calibration values obtained using the methodology of Uchiyama et al (2019). Also, we plan to improve the coefficients.
- Based on the successful comparison of AERONET and PREDE in Tor Vergata, we plan to prepare a manuscript for its submission to an international peer reviewed journal such as Atmospheric Measurement Techniques.

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