Remote Sensing of Aerosol Optical Depth (AOD) over Pretoria, South Africa.

Z Faniso[1], E Magimisha[1] and T Malatji [1]

CSIR, Defense and Security, Meiring Naude Road, Brummeria, Pretoria 0001

E-mail: ZFaniso@csir.co.za

Abstract. This paper presents the analysis of Aerosol Optical Depth (AOD) level data monitored through the Cimel CE 318A Sun-photometer over the year seasons of 2014. The data was collected at the Council for Scientific and Industrial Research (CSIR), Department of Defence and Security (D&S) in Pretoria (PTA), South Africa. The Aerosol Robotic Network (Aeronet) instrument was placed at the roof-top of a building and has been recording and providing continuous atmospheric AOD data from 2011 until 2018. The atmospheric aerosols contribute to atmospheric scattering and absorption within the Visible to Near-Infrared (VISNIR) band and can severely affect the performance of remote sensing imaging systems. The AOD measurement data can therefore be used as an input in the performance of the calibration validation process of Earth Observation (EO) sensors and other long-range target detection and recognition systems. The Optronic Sensor Systems (OSS) of the Defence and Security (D&S) cluster focuses on building optical imaging systems for satellites EO, short-range and long-range surveillance applications. The reported data is an extract of measurements obtained over a year when the instrument was in operation at the D&S. This work provides the necessary exposure in building the capability and confidence in the evaluation of the performance of remote sensing systems.

1. Introduction

Spaceborne remote sensing of aerosol particles, evaluation of the aerosols' climatic effects, and atmospheric corrections of imageries from Earth Observation (EO) systems mainly involves the understanding of the spectral Aerosol Optical Depth (AOD). AOD is the measure of aerosols (e.g., urban haze, smoke particles, desert dust, sea salt, etc) distributed within a column of air from the instrument (Earth's surface) to the top of the atmosphere [1]. It is a degree by which the aerosols prevent the transmission of light from reaching the earth's surface by absorbing and scattering the light. The Aerosol Radiative Forcing's (ARF) is one of the largest uncertainties in climate change. They are known to significantly influence the radiative budget of the Earth's atmosphere, both directly by scattering and absorbing radiation and indirectly by affecting cloud properties [1]. Precise and consistent measurements of aerosol optical properties, such as AOD, single scattering albedo, and phase function are key parameters to the aerosol direct effect [8]. The study will analyse AOD measurements from Pretoria (PTA), South Africa where the Aeronet instrument was previously installed.

Pretoria is an inland area that can be easily affected by large amounts of aerosols that contribute massively to the climate and radiative transfer over the area. The major industries in PTA includes those which manufacture motorcycles, chemicals, pharmaceuticals, engineering products, construction materials, steel industries, and cement factories. In addition to the industrial emissions, other anthropogenic sources that include vehicular emissions from main highways, coal combustion, agricultural and biomasses burning are the major local sources of aerosols in this capital city of South Africa [5]. To monitor the aerosols levels, various radiometric systems have been used to measure AOD which include Micro tops II Sun photometer a handheld analog instrument that measures AOD.

However, the accurate knowledge of the spatial and temporal extent of aerosol concentrations and properties has been a limitation for assessing their influence on satellite remotely sensed data and climate forcing [2][9]. Hence the National Aeronautics and Space Administration (NASA) developed an

Aeronet (Aerosol Robotic Network), a UNIX-based near real-time processing, display, and analysis system providing internet access to the emerging global database [2]. This global network installs CIMEL Sun-photometers for monitoring AOD and aerosol optical properties for AOD trend analysis, optical properties characterisation, and validation of satellite retrievals see Figure 1[3]. The Cimel systems data require validation and monitoring to ensure stability and use for calibration and validation of space sensors.

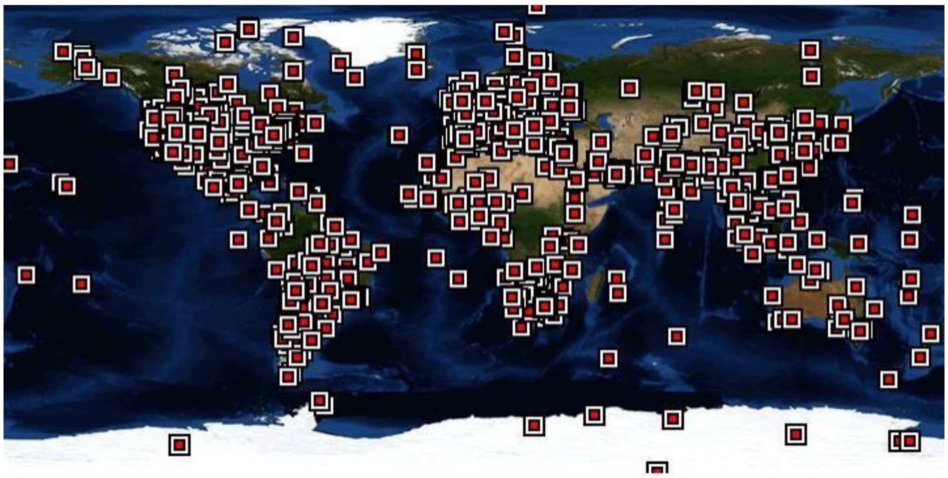

Figure 1: Aeronet ground based remote sensing instrument installations

The Council for Scientific and Industrial Research (CSIR) is the host to one of the Aeronet ground-based sun photometers (Cimel-318 Sunphotometer) that is used to monitor the atmospheric AOD distribution levels. The current study reviews the Cimel-318 AOD data captured in 2014. The instrument had captured full data(for all the months) for the year 2014. The other years encountered interruptions which lead to the instrument missing data. The 2014 data is analysed for all the seasons (Summer, Autumn, Winter and Spring) to evaluate the data stability for future validation of optical space sensors.

2. Methodology

2.1. Cimel-318 Sunphotometer Installation at CSIR

The Council for Scientific and Industrial Research (CSIR) Aeronet Cimel-318 Sunphotometer was installed at the roof-top of building 44, that is at 1449 m above sea level with a clear spatial view of the surrounding areas and no obstructions from nearby objects. The system was installed at -25.756611° S latitude and 28.279722° E longitude (see Figure 2). Some estimates suggest that anthropogenic aerosols and biomass burning have climate forcing enough to offset the warming caused by Green House Gases (GHGs) such as carbon dioxide [4]. Ground-based remote sensing has become a powerful method for characterising atmospheric aerosols as it can present a clear picture of the optical properties of each of the aerosol species [4]. OSS Aeronet Cimel-318 Sunphotometer installation contributes to the calibration and validation of space optical surveillance systems, Satellites sensors, Air quality and climate change research study sensors etc.

 ISBN: 978-0-620-97693-0

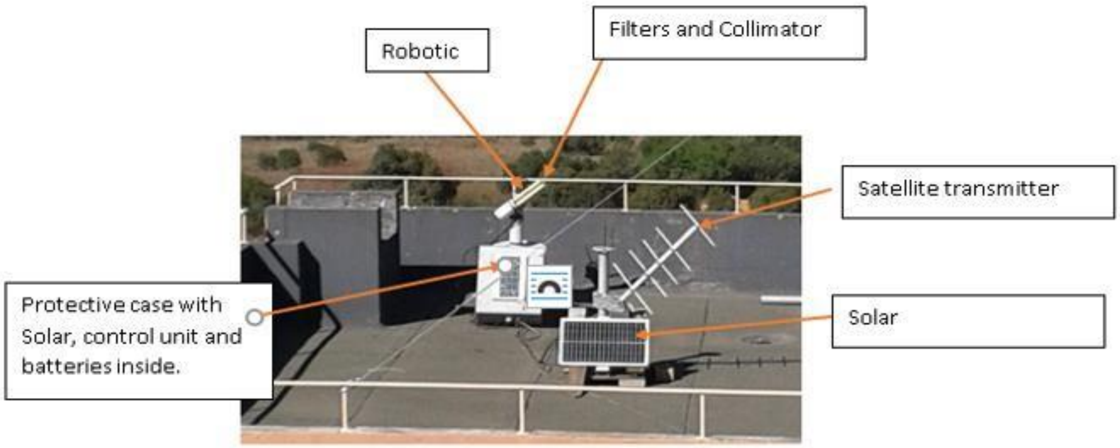

Figure 2: Cimel 318 Sunphotometer installation at CSIR/D&S Building

For more than 25 years, the project has provided a long-term, continuous, and readily accessible public domain database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases [3]. The CIMEL318 Sunphotometer makes direct spectral solar radiation measurements within a 1.2° full field of view at a typical temporal repetition interval of 15 min. The solar radiance is sampled at 8 standard band filters from 340 nm, 380 nm, 440 nm, 500 nm,675 nm, 870 nm,1020 nm, and 1640 nm [5]. These filter bands are contained by the robotic part of the system, and each region from visible to short wave is represented by atleast two filters. The Satellite transmitter data sends the data automatically to 4 Satellites: GOES East, GOES West, Meteosat and Geostationary Meteorological Satellite GMS using Data Collection Platform (DCP). Data are transferred from satellites to Aeronet processing server via several receiving stations. The case is the component where the Control Unit (CU)and the pair of batteries are placed. The solar panel that powers the system is incorporated in the case. The output plug of the solar panel is a RJ11 connector. The instrument batteries supply power to the CU. The battery is 8AH. The YUASA battery is furnished when the satellite transmitter is used. The battery is 24AH. The Mascot 2240 battery charger is used only in case of solar panel breakdown [5].

Figure 3 shows the atmospheric scenario that generally explains what the Cimel instrument is exposed to while in operation. Various aerosol types are suspended in the atmosphere affecting the sun radiation propagation towards the earth surface. The Cimel sun photometer employs the sun as reference in determining the atmospheric AOD from aerosols floating in the path between the Sun and the instrument.

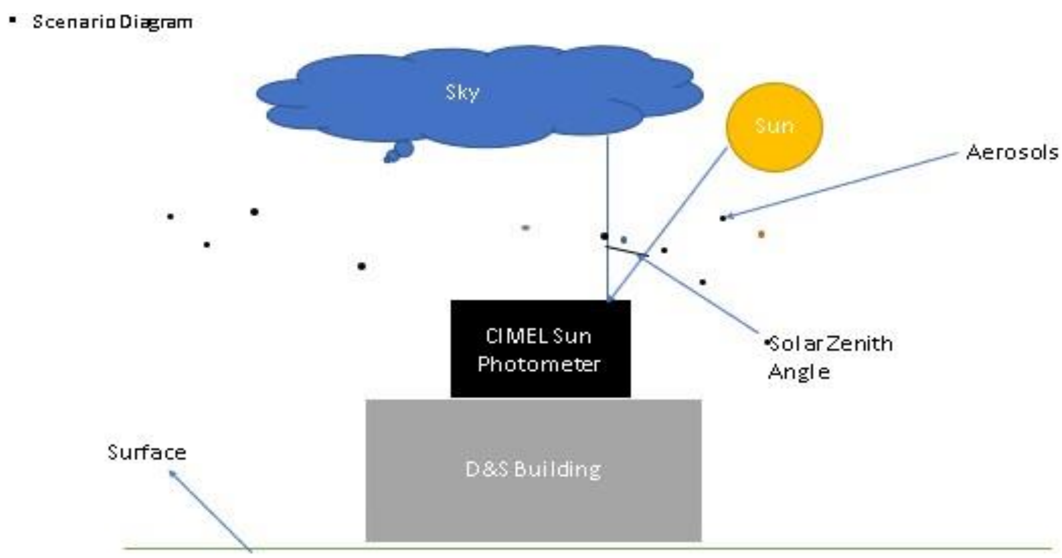

Figure 3: Atmospheric scenario for the Cimel-318 Sunphotometer at CSIR/D&S building

Depending on the abundance of the atmospheric aerosols, the solar radiation can either be absorbed, reflected and some transmitted to the earth surface.

2.2 AOD Measurements

The city has a humid subtropical climate with long hot and rainy summers, and short cool and dry winters [5]. The data from the PTA station can be found on the AERONET website (http://aeronet. gsfc.nasa.gov/). AOD data are computed for three data quality levels, Level 1.0 (unscreened), Level 1.5 (cloud-screened and quality controlled), and Level 2.0 (quality assured) [3]. The version 2.0/level 2.0 of the quality assured daily points' format data of direct sun and inversion products are used for the study period of the year 2014.

The effect of radiative transfer is proportional to the amount of particles present in the column and depends on their intrinsic optical properties. The spectral variation of AOD provides useful information on columnar size distribution and can be best represented by Ångström power law relationship, given by Ångström (1964) [4].

$$\tau_a(\lambda) = \beta\lambda^{-\alpha} \quad (1)$$

Where τ_a (λ) is the AOD at wavelength λ (in micrometers), β is the turbidity coefficient, indicating total aerosol loading, which equals to τ_a at $\lambda = 1$ μm, and α is widely known as the Angstrom exponent (AE), which is a good indicator of aerosol particle size [4]. AE largely depends on aerosol size distribution and is a measure of the ratio of coarse- to fine-mode aerosols [4].

$$\alpha = -\frac{\beta\lambda}{\text{Ta}} \quad (2)$$

with higher values representing the increased abundance of fine-mode aerosols and lower values representing the increased abundance of coarse-mode aerosols. Aerosol size distribution in turn depends on their production mechanism, e.g. particles formed by gas-to-particle conversion are small particles whereas particles formed by mechanical actions such as wind lifting of dust, wave-breaking, etc. are bigger[4].

3. Results and Discussion

The aerosol optical depth is representative of the airborne aerosol loading in the atmospheric column. For this current study seven of the eight bands AOD data has been analysed. Figure 4 illustrates the average mean of the retrieved AOD data while Figure 5 illustrates the $AE_{(440\alpha\text{-}870)}$ average mean data for each month of the year 2014 in PTA. All the seasons of the year are shown, however seasons of the year vary in temperatures with winter consisting of dry, cool to low-temperature experiences while summer experiences high temperatures with heavy rainfalls. The Aeronet AOD data showed an increase in the AOD rate from January with a maximum of +-0.3 and swiftly drops in May to a minimum of +-0.10 (see Figure 4). May is the first month of the winter season and PTA winter season mostly shows clear and uncloudy sky with the soft wind that contributes to the transfer of dust particles in the atmosphere. An AOD growth is observed from the end of May which spreads along to June and July with a maximum between +-0.2 and +- 0.23 still lower than the Autumn season (February, March, and April). The winter season is followed by another drop at the mid-spring season (August, September, and October) and shows an increase again in the summer season with a maximum of +- 0.35.

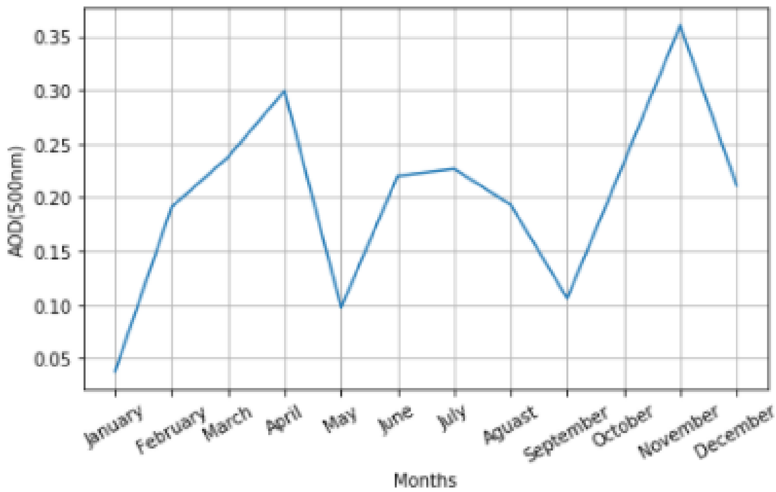

Figure 4: AOD average mean data from January to December 2014

A comparison between the AOD (Figure 4) and AE (Figure 5) has been performed. It has been observed that the two data sets project the same trend for all the seasons of the year. The AE (Angstrom Exponent) shows the increase from January and decrease in May with an increase in winter season followed by a drop in mid-Autumn season and a huge increase in the summer season. The AE has shown that it is dependable to the AOD rate.

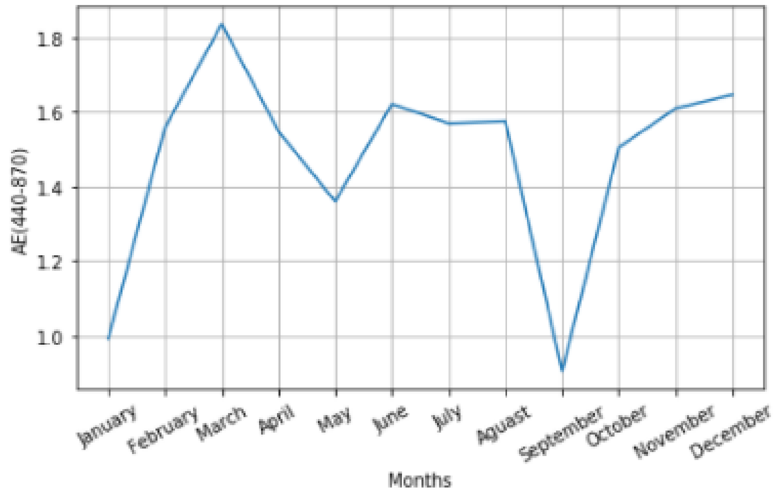

Figure 5: The Angstrom Exponent data for the year 2014.

In terms of monthly variations Figure 6 and 7 filter variations between Cimel sensors from visible to infrared range.

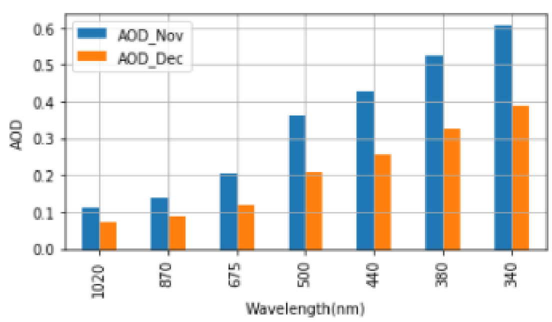

Figure 6: Comparison of AOD for the summer season (AOD_November and December). Of 2014.

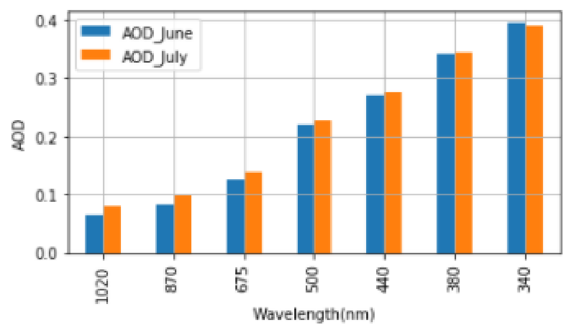

Figure 7: Comparison of AOD for the winter season (AOD_June and July) of 2014.

The summer season commences with November where there is a high peak in AOD with +- 0.6, followed by December (see Figure 6) with a maximum of +-0.39. December experiences high temperatures accompanied by heavy rainfalls. These heavy rainfalls may contribute to shutting the Cimel sensor since it only performs measurements when the Sun is actively radiating the Earth surface without interruptions. The occurrence of high value in urban regions was also related to the anthropogenic pollution and local prevailing meteorological condition. This implies that there were Aerosols over PTA within the winter season (June/July) see Figure 7. The two months show almost equal amount of AOD in each sensor. This is because the winter season experiences almost the same temperatures without drastic changes as compared to summer (see Figure 4 and 6).

4. Summary

The analysis of Aerosol Optical Depth profile and Angstrom exponent (AE) data from the Aeronet Cimel-318 Sun photometer based at the CSIR in PTA was performed. A year data (from January to December) of the year 2014 has been used in the present study. The data was downloaded from the AERONET webpage to analyse the AOD of the aerosol loading in association with local aerosol conditions behaviour and estimated the atmospheric radiative forcing around the area. The aerosol optical depth (AOD) showed the highest rate occurring in November and December respectively, while the lowest was noticed in June and July. In the PTA city, the summer season is known to experience heavy rainfalls with dry winter seasons with mostly uncloudy days. It is significant to continuously monitor aerosol properties to assess more accurately and characterize the annual cycle since only one year of data has been used in the present study.

References

[1] K.K Raghavendra, S Venkataraman, R. R Rajuru and R.G Kotalo, SPIE, 2016, Remote sensing of atmospheric aerosols in South Africa.

[2] B.N Holben, T.F.Eck, I.Slutsker, D.Tanre, J.P.Buis, A.Setzer, E.Vermote, J.A.Reagan, Y.Kaufman, T.Nakajima, F.Lavenu, I.Jankowiak and A.Smirnov,1998:AERONET Afederated instrument network and data archive for aerosol characterisation, Rem.Sens. Environ.,66,1-16.

[3] https://aeronet.gsfc.nasa.gov

[4] A.J. Adesina, K.R Kumar, V.Sivakumar, and D.Griffith, 2014, Direct radiative forcing of urban aerosols over Pretoria(25.75 D,2828 E) using AERONET Sunphptometer data First Scientific results environmental impact Journal of Environmental Sciences, 26(12), pp.2459-2474.

[5] Multiband and photometer CE318-T User's Manual(rev.January 2018).

[6] Y.J.Kaufman, 1993. Aerosol optical thickness and atmospheric path radiance. Journal of Geophysical Research:Atmospheres, 98(D2), PP.2677-2692.

[7] X.Y. Zhang, Y.X.Xiong, J.J.Qu,and H.Che,2011. Validation of MODIS aerosol optical depth product over China using CARSNET measurements. Atmospheric Environment, 45(33), pp.5970-5978.

[8] B.N Holben, T.I.Eck, I.Slutsker:D.Tar&',6 J.P Buis,II A.Setxer, J.E Vemte,' J.A Reagan, F.Y.J Kaufman, T.Nakajima,1:F.Lavenu,qqI.Jankowiak and A.Smirnozit, 1998. ELSEVIER AERONET A Federated Instrument Network and Data Achirve for Aerosol Characterisation.

[9] Kumar, P., Choudhary, A., Singh, A.K., Prasad, R. and Shukla, A., 2020. Aerosol parameters during winter and summer seasons and meteorological implications. In EPJ web of conferences (Vol. 237). EDP Sciences.

 ISBN: 978-0-620-97693-0