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Article

An Overview of Hand held Sun Photometer Measurements of Atmospheric Aerosols in New Orleans, Louisiana*:* A case study of the Xavier University study site

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Abstract: Aerosol optical depth (AOT) was measured at Xavier University of Louisiana (29.96° N, 90.11° W and about 3m above sea level) using a hand-held sun photometer. AOT was measured at two different wavelengths (green at 505nm and red at 625nm) during the period from Sept-2017 to Feb-2018. In this study, we investigate the relationship between AOT and temperature, precipitation, barometric pressure and relative humidity. The maximum monthly average value for green AOT was 0.176 (measured in September) and the minimum monthly value is 0.040 (measured in January). For the red AOT the maximum monthly average value was 0.123 (measured in September) and the minimum is 0.034 (measured in December). The AOT–temperature relationship was predominantly positive, meaning that high AOT values correspond to high temperatures and low AOT values correspond to low temperatures. Relationship between AOT and rainfall is negative, meaning high rainfall averages are associated with low AOT values. AOT and atmospheric pressure have a predominantly negative relationship. The relationship between relative humidity and AOT is a complicated one and is hard to qualify as relative humidity varies very little during the study period.

Keywords: Sun photometer, Aerosols, Aerosol Optical Depth (AOT), New Orleans

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1. Introduction

The atmosphere is made up of molecules of gas and small solid and liquid particles suspended in the air, called aerosols [1, 2]. Some aerosols are naturally produced from volcanoes, sea spray, sand, or wind-driven erosion of surface soil [3]. Some aerosols are a result of human activity, such as dust from agricultural activities, smoke from burning biomass and fossil fuels and photo chemically induced smog due mostly to vehicle emissions. Drops and ice crystals that form when water vapor freezes or condenses are also aerosols. Aerosols are too small to be individually seen by the naked eye, but you can often see their collective effect when the sky is smoky or looks dirty. Bright orange skies at sunrise and sunset may also be pointers that aerosols are present [4].

Aerosols impact our weather and climate because they affect the amount of sunlight reaching earth's surface. Biomass burning causes large local increases in aerosol concentrations that can affect regional weather. Taken together with other atmospheric measurements, aerosol measurements help scientists to better understand and predict climate

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and to understand atmospheric chemistry [5, 6]. Aerosol concentrations vary considerably with location and time. There are seasonal and yearly changes as well as random changes due to events such as large dust storms and volcanic eruptions [7, 8]. Aerosols are extremely mobile; they can cross oceans and mountain ranges. It is universally agreed that, because of higher concentrations of aerosols, skies in many parts of the world are hazier than they were one or two centuries ago, even in rural areas. Aerosol optical thickness (AOT, also called aerosol optical depth) is a measure of the degree to which aerosols affect the passage of sunlight through the atmosphere [9, 10, and 11]. The larger the optical thickness at a particular wavelength, the less light of that wavelength reaches Earth's surface. Measurements of aerosol optical thickness at more than one wavelength can provide important information about the concentration, size distribution, and variability of aerosols in the atmosphere [12, 13]. This information is needed for climate studies, for comparison with satellite data and to understand the global distribution and variability of aerosols. Aerosol measurements are best understood in the context of the other atmospheric measurements [14]. There may be observable relationships between aerosols and temperature, precipitation, relative humidity or barometric pressure. Thus, it is helpful to approach this study as part of a big picture of the atmosphere and its properties.

The main goal of this study is to measure the aerosol optical thickness of the atmosphere at our study site over several seasons. This paper presents data for a six months period from September 2017 to February 2018. This is the first ever AOT recorded for this site. With this data we investigate to what extent AOT is related to other atmospheric variables such as temperature, precipitation, relative humidity and barometric pressure. Global measurements are needed to monitor the present distribution of aerosols and to track events that alter aerosol concentrations. Their study can lead to a better understanding of earth's climate and how it is changing. By reporting measurements regularly at a local level, we provide scientists with the data they need, and we can start to answer some questions about aerosols for our own study site. By building a data record that extends across several seasons, we can help scientists learn more about the distribution of aerosols in our study site.

2. Site, Instrument and Method

2.1. Site and Meteorology

The study site is at Xavier University of Louisiana (29.96N, 90.11W) which is in downtown New Orleans, Louisiana, USA. The City of New Orleans is located on the Mississippi river in southeastern Louisiana. The large Lake Pontchartrain also lays within the city limits. It is about 169km north of the Gulf of Mexico. New Orleans has a humid subtropical climate with very hot and humid summers and mild, short-lived winters. Summers in New Orleans are relatively long with high temperatures hovering around 90°F from May to September. In

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winter, from December to February, temperatures average between 44°F and a comfortable 62°F. New Orleans experiences high annual rainfall, most of it falling in mid-late summer, often as a spin-off from tropical storms. Heavy rain during the June to September Gulf Coast hurricane season has occasionally caused flooding in the city. Snow and ice are rarities in New Orleans, but there have been three incidences of light snowfall in the past ten years.

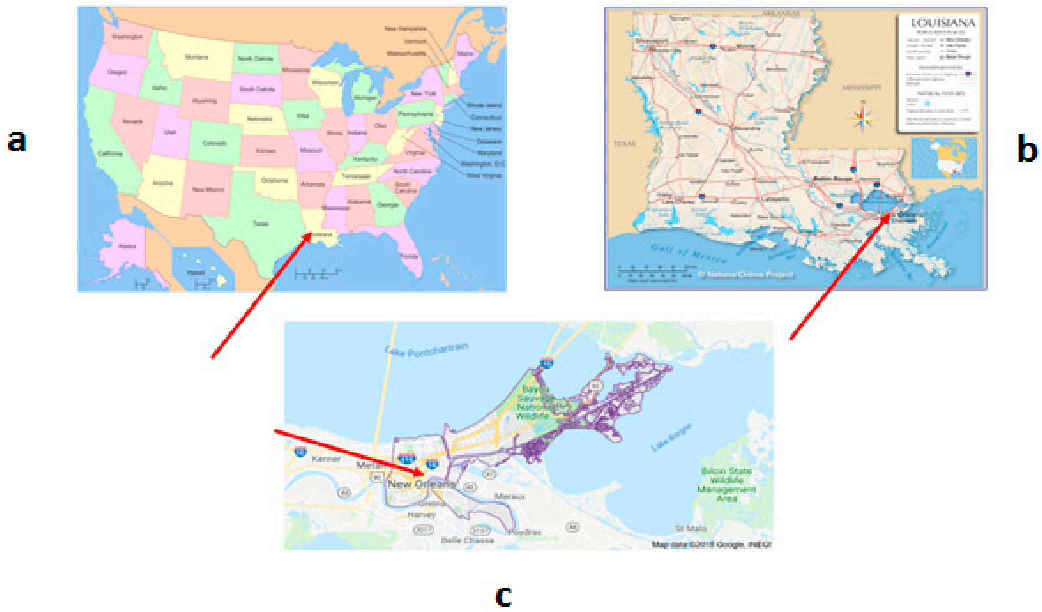

Figure1. Location of New Orleans, Louisiana, USA: (a) location of the state of Louisiana in USA; (b) location of New Orleans in the state of Louisiana; and (c) Study site at Xavier University of Louisiana.

2.2. Instrument and Method

A sun photometer is an electronic device that measures direct sunlight over a narrow range of wavelengths [15]. That is, it measures light of a particular color. The GLOBE (Global Learning and Observations to Benefit the Environment) sun photometer has two channels, each of which is sensitive to a particular wavelength of light — green light at wavelength 505nm and red light at wavelength 625nm. Green light is near the peak sensitivity of the human eye; hence, a visibly hazy sky is likely to have a large aerosol optical thickness at this wavelength. Red light is more sensitive to larger aerosols. Data from a single channel enables the calculation of AOT for a particular wavelength [16, 17]. The Globe sun photometer was purchased from IESRE (Institute for Earth Science Research and Education: serial # RG8-989). It uses light emitting diodes as detectors.

Figure 2 below shows an inside and outside view of the GLOBE sun photometer. It is housed in a plastic case about 15x8x5 cm (6"x3"x2"). On the top of the case, there are two

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alignment brackets. In use, the instrument is pointed at the sun so that light passes through the hole in the front bracket and makes a bright spot that shines on a piece of paper covering the rear bracket. The two LED detectors in the GLOBE sun photometer respond to red or green light. Figure 2a shows an inside view of the sun photometer case. The view is from the front of the case, looking toward the rear, The LED detectors are located just to the left of the center of the green printed circuit board. The battery is behind the printed circuit board. When sunlight strikes one of the LEDs, it produces a very small current which is then amplified and turned into an output voltage. The output voltage is what is measured. The output voltage is affected by the concentration of particles (aerosols) in the atmosphere. The higher the concentration of aerosols, the smaller the amount of sunlight reaching the detector, and the smaller the sun photometer's output voltage. The instrument was calibrated using the Langley plot method [18, 19]

Students for the Advanced Earth Science class (PHYS4010) at Xavier University collect atmospheric data every day. This data includes temperature, precipitation, relative humidity and barometric pressure. They do this following the GLOBE atmospheric protocols and enter all the data in the GLOBE data base. Measurements of AOT are done every day when the weather conditions are permitting. Sun photometer measurements can be interpreted properly only when the sun is not obscured by clouds. Cirrus clouds often present difficult problems when taking sun photometer measurements. These clouds are often thin and may not appear to block a significant amount of sunlight. However, even very thin cirrus clouds can affect sun photometer measurements.

The logical place to take sun photometer measurements is the same place where we do our cloud observations and other atmosphere protocols. Ideally, aerosol measurements are done in the morning when the solar elevation angle is at least 30 degrees. This is because, generally, the air in the morning is less turbulent than air near noon when the sun is high in the sky. The less turbulent the air, the easier it is to obtain reliable measurements.

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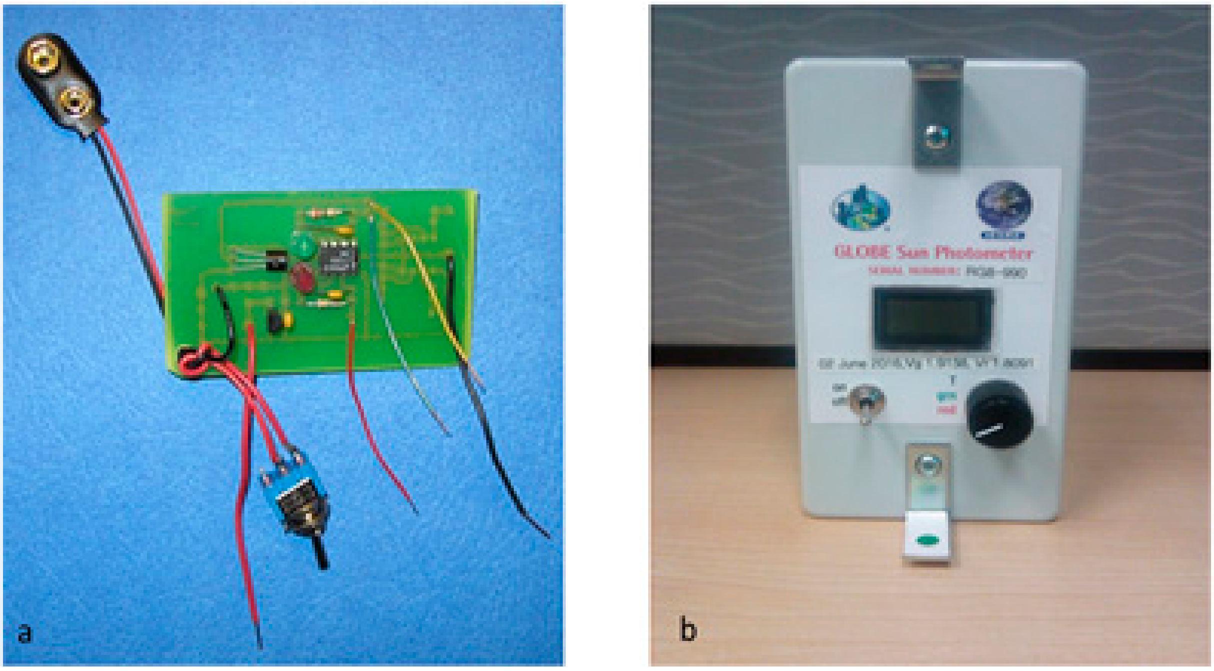

Figure2. The GLOBE hand held sun photometer. (a) Basic circuit of the GLOBE sun photometer, (b) A fully assembled sun photometer.

Measurements taken with the GLOBE sun photometer are in units of volts. These values are then converted to aerosol optical thickness using the equation shown below [20]:

$$AOT = \left[\frac{ln\left(V_0/_R\right) - ln(V - V_{dark}) - a_R\left(P/_{P_0}\right)m}{m} \right] \quad (1)$$

V_0 is the calibration constant of sun photometer, **R** is the earth-sun distance expressed in astronomical units **V** and **V_{dark}** are the sunlight and dark voltages from sun photometer, **a_R** is the contribution to optical thickness of Rayleigh scattering of light, in the atmosphere, **P** is the station pressure at the time of measurement, **P_0** is the standard sea level atmospheric pressure, **m** is the relative air mass (m=1/ sin (solar elevation angle). The values of V and V_{dark} are also entered into the GLOBE data base in order to obtain the GLOBE calculated AOT values

3. Results and Analysis

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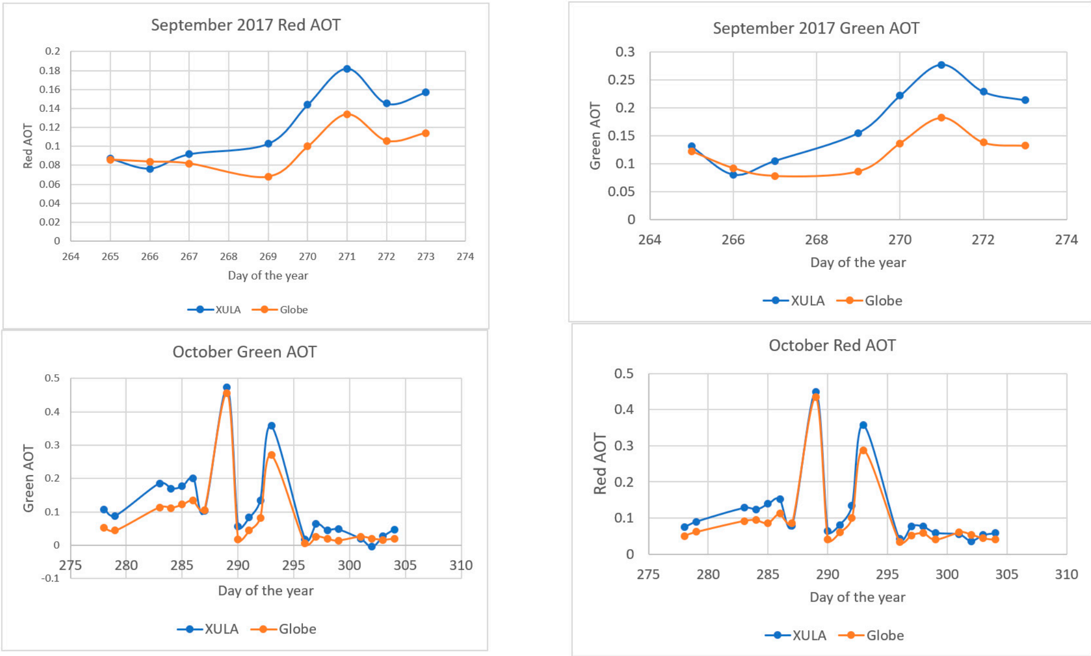

Figure 3. The calculated values of red and green AOT (Xula) for the months of September and October compared with the AOT values from GLOBE (Globe) for the same period

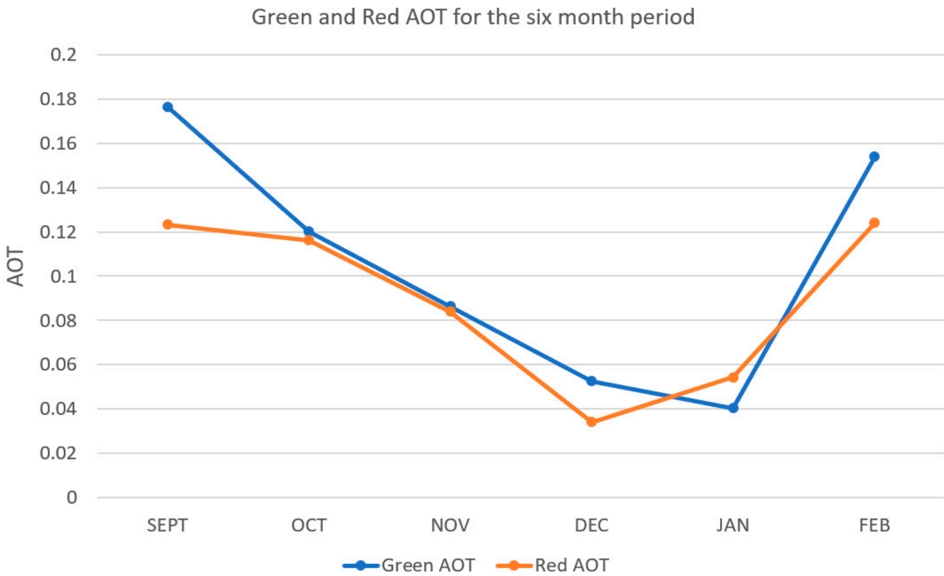

Figure 4. The variation of the monthly average of the green and red AOT values for the six month period from September 2017 to February 2018.

Figure 3 shows a sample of how our calculated values of AOT (XULA) compare with the AOT calculated by GLOBE. We see that our values and the Globe values are in agreement in most cases and in some cases they are exactly the same. This gave us confidence that our calculations are correct. Figure 3 shows data for September and October only. Data for the other months show the same trends.

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Figure 4 shows variation of the green AOT and red AOT over the six months period. The data shows that the AOT for green light drops continuously from September to January and then picks up in February. The AOT for red light follows a similar trend but reaches a minimum in December and starts going up for January and February. It is seen from Figure 4 that the green AOT is typically higher than the red AOT except for the month of January. This is due to the fact that typical aerosols scatter green light more efficiently than red light. The maximum value for green AOT is 0.176 (September) and the minimum value is 0.040 (January). For the red AOT the maximum value is 0.123 (September) and the minimum is 0.034 (December). This data shows that in general the attenuation of sunlight caused by aerosol is increased with decreasing the wavelength.

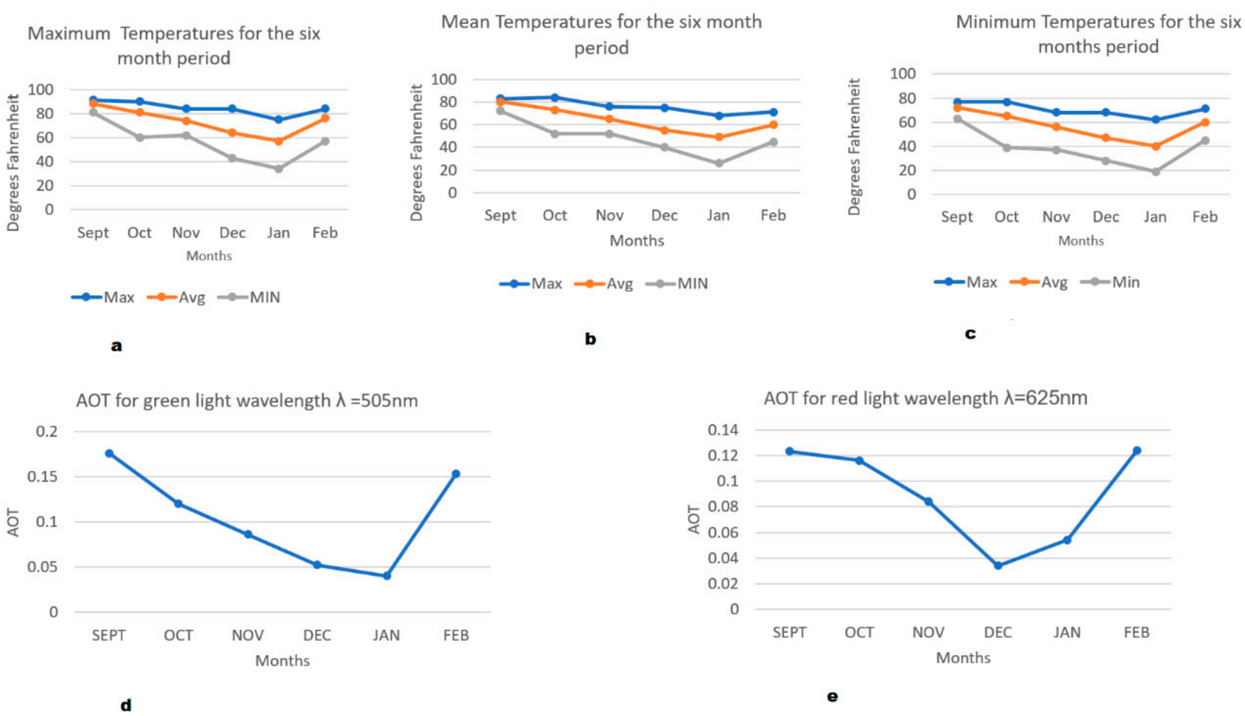

Figure 5. Figure shows how the temperature variations compare with AOT variations over the six month period. (a) Variation of the Maximum temperatures, (b) Variation the monthly Mean temperatures, (c) Variation of the Minimum temperatures ad (d, e) Variation of the monthly average of the green and red AOT values during the six months period.

The thermometer used for measuring temperature has two temperature probes that capture data independently of one another. The thermometer collects and stores the current day temperature, plus six days of MAX/MIN temperature data. We used the daily current temperatures to calculate the monthly Mean temperatures shown in figure 5b. The general trend of all the three temperature measurements shows a continuous decrease from September to January and then starts picking up in February. The data show that the AOT for green

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follows a similar trend to the three temperature trends i.e. it drops continuously from September to January and then picks up in February. The AOT for red light follows a similar trend but reaches a minimum in December and starts going up for January and February. The AOT–temperature relationship is predominantly positive, meaning that higher AOT values correspond to high temperatures. Typically, we expect to have predominantly negative AOT-temperature relation because aerosols decrease the net energy absorbed from the sun by reflecting sunlight back into space. Also, certain types of aerosols generate an increase in temperature by chemical breakdown into greenhouse gasses. However, in this case since the low temperatures also coincide with high rainfall, the unexpected low AOT values maybe attributed to rain wash-out of the aerosols in the atmosphere.

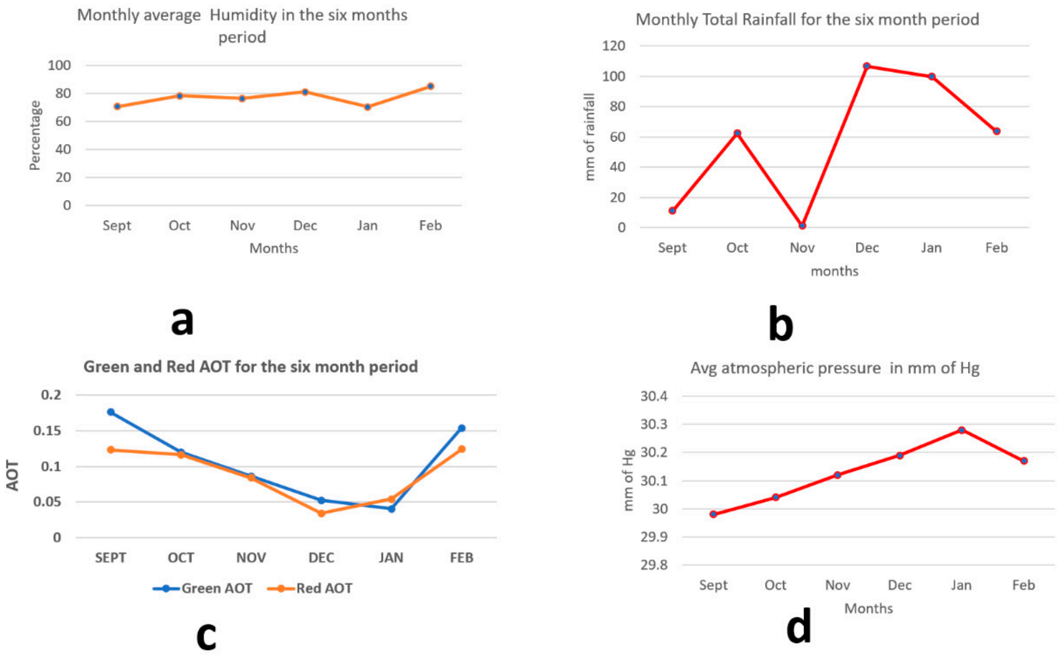

Figure 6. Comparison of AOT variations with other atmospheric parameters in the six months study period: (a) Variations of Relative humidity, (b) Variation of rainfall, (c) Variation of AOT and (d) Variation of atmospheric pressure.

Figure 6a shows the variation of Relative humidity in the 6 months period. The relative humidity increased slightly from about 70% in September to about 80% in October. It remained steady from October to December and then deeps to about 70% in December. In contrast Figure 6c shows that the AOT for green light drops continuously from September to January and then picks up in February. The AOT for red light follows a similar trend but reaches a minimum in December and starts going up for January and February. The relationship between relative humidity and AOT is a complicated one because other factors such as rainfall are also involved. In general, relative humidity is associated with rainfall and has great influence in condensation process that reduces the number of particles in the atmosphere by rain wash-out and gravitational settling, which lowers AOT values.

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Hygroscopic growth of aerosols in a humid environment may change their physical and optical properties. These changes can increase or decrease AOT values depending on the nature of the aerosols. In this sense the high values of rainfall in December January and February are consistent with the low values of AOT as expected. Atmospheric pressure is continuously increasing from September to January and then drops a bit in February. Comparing figure 6c with figure 6d, we see an inverse relation between AOT and atmospheric pressure. This AOT-atmospheric pressure relationship is consistent with equation 1 above.

4. Conclusions

Sun photometer measurements were used to calculate AOT variations over a six months period from September 2017 to February 2018. During this period atmospheric parameters like temperature, relative humidity, rainfall and atmospheric pressure were also recorded. The maximum monthly AOT values appeared in September for both green light (wavelength 505nm) and red light (wavelength 625 nm). The minimum monthly AOT values appeared in January for the green light and in February for the red light. There was a predominantly positive AOT-temperature relationship in the six-month study period. The AOT- rainfall relationship and the AOT-atmospheric pressure relationship were predominantly negative in the same period. The relationship between AOT and relative humidity during the same period was hard to quantify. As discussed above this relationship is complicated. To understand this relationship, we need to do more to find the nature of the aerosols in our study site. In addition, long-term observed data are required to improve our understanding of how aerosols affect or are affected by other atmospheric parameters. It is also necessary to obtain AOT data from more than two channels to get information on size distribution of the aerosols. Knowing the size distribution help to identify the source and nature of the aerosols. The authors know that the data set given here is not sufficient enough to provide a sound analysis, thus the conclusions of the present study cannot be far-reaching. A much more detailed and long-term investigation of aerosol at the site is underway.

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Author Contributions

The work presented here was carried out in collaboration between all authors. Morewell Gasseller defined the research theme, designed methods, interpreted the results and wrote the manuscript. Maryssa Bradley carried out the measurements, analyzed the data, carried out the AOT calculations and edited the paper. Barry Savalia was involved with the initial assembly and testing of the sun photometer. All authors have contributed to, seen and approved the manuscript. In summary: Data curation, Maryssa Bradley; Formal analysis, Morewell Gaseller; Writing – review & editing, Barry Sevalia.

Conflicts of Interest

The authors declare no conflict of interest.

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