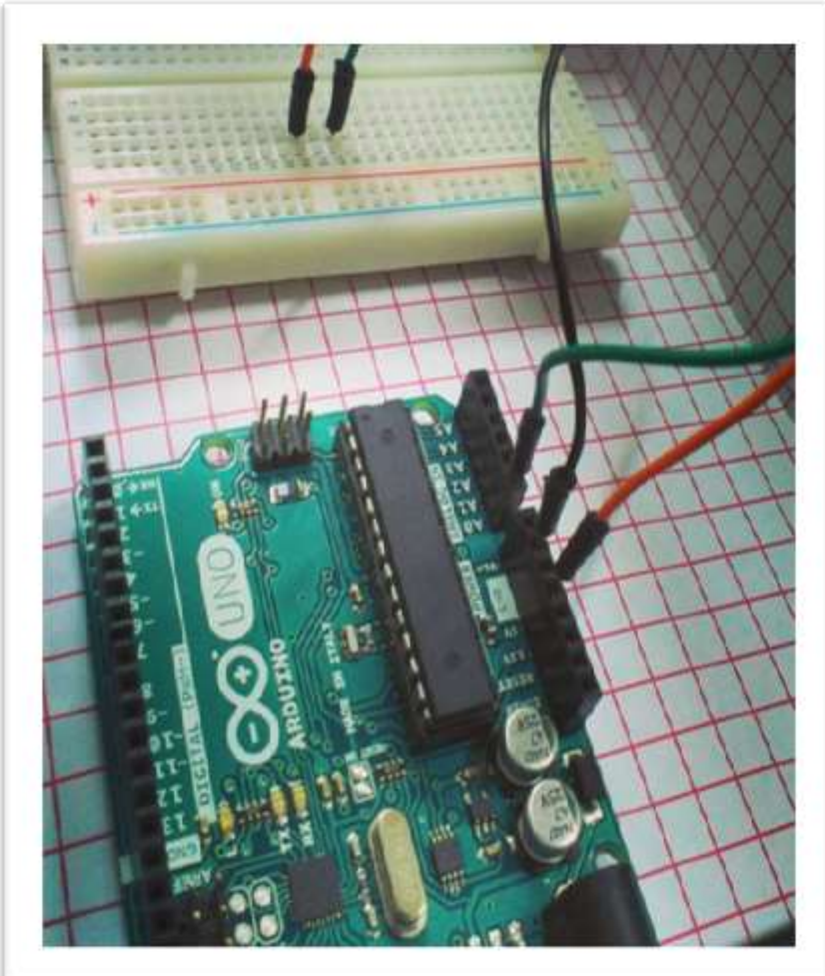
King Abdul-Aziz University
Faculty of Science
Physics Department
2nd term
1436 -2015



Measuring Aerosols with Arduino

AT KING ABDULAZIZ UNIVERSITY

Suaad Alsaggaf, Nouf Algamdi, Fatimah Salem, Azza Alsulami
Supervised by: Dr. Hala Aljawhari

Abstract

A new device for measuring the aerosols optical thickness with Arduino had been constructed. The device has two parts: software and electronic circuit as a hardware. It works according to a simple principle that is based on converting the analog signal to a digital one i.e. measuring the sunlight intensity and converting it to electrical signals in volt. The resulted data were used to calculate the aerosols optical thickness (AOT) at King Abdul-Aziz University. Our readings showed a little increase in the average value of AOT compared to previous measurements. However, such deviation was expected as our measurements were taken with different device and for short time period.

Introduction

Monitoring atmospheric aerosols is one of the active fields that captured the interest of many researchers all over the world. One of the recent studies in this is the work done by Farahat et al [1], in which they measured the AOT at some regions of Saudi Arabia. In specific; they measured the AOT for; Rub AlKhali, Dhahran, Tabuk and Makkah.

The reason for this interest is that aerosols improve numerical models used to develop strategies for sustainable development and achieve a balance between energy needs with the need for a stable environment.[2]

The aim of our work is to measure the aerosol optical thickness (AOT) in the city of Jeddah, Saudi Arabia. More precisely, the measurements will be taken inside the campus of King Abdul-Aziz University.

What are Aerosols?

Aerosols are tiny solid particles and liquid droplet suspended in the atmosphere. Its size varies from nanometers to several micrometers. Despite their small size, they are important for scientists to understand Earth's climate system. The effect of aerosols differs depending upon their size, type, and location, aerosols can either cool the surface, or warm it. In addition, they can help clouds to form, or they can inhibit cloud formation. And if inhaled, aerosols can be harmful to people's health.

Windblown dust, sea salts, volcanic ash, smoke from wildfires, and pollution from factories are all examples of aerosols [3].

Aerosols interaction with light

The interaction of sunlight with aerosols through passing the atmosphere, undergoes scattering, reflection and absorption. An aerosol’s effect on light depends primarily on the composition and color of the particles. Broadly speaking, bright-colored or translucent particles tend to reflect radiation in all directions and back towards space. Darker aerosols can absorb significant amounts of light. The type of interaction depend on the size of aerosols and can be classified to direct effect and indirect effect. [3]

Direct effect: They reflect sunlight back to space. Although most aerosols reflect sunlight, some also absorb it.

There are two types of direct scattering, "**Mie**" and "**Rayleigh**" scattering.

Rayleigh scattering is scattering light to all directions and it is caused by all molecules and particles in the atmosphere.

Mie scattering is defined as the interaction of light with (particulate) matter of dimensions comparable to the wavelength of the incident radiation [4] [5].

Indirect effect: occurs when light interact with clouds and the detailed microphysics of clouds. Whereas aerosols can influence climate by scattering light and changing Earth's reflectivity, they can also alter the climate via clouds. On a global scale, the aerosols "indirect effects" typically work in opposition to greenhouse gases and cause cooling. While greenhouse gases disperse widely and have a fairly consistent impact from region to region, aerosols effect are less consistent, partly because of how the particles affect clouds [3].

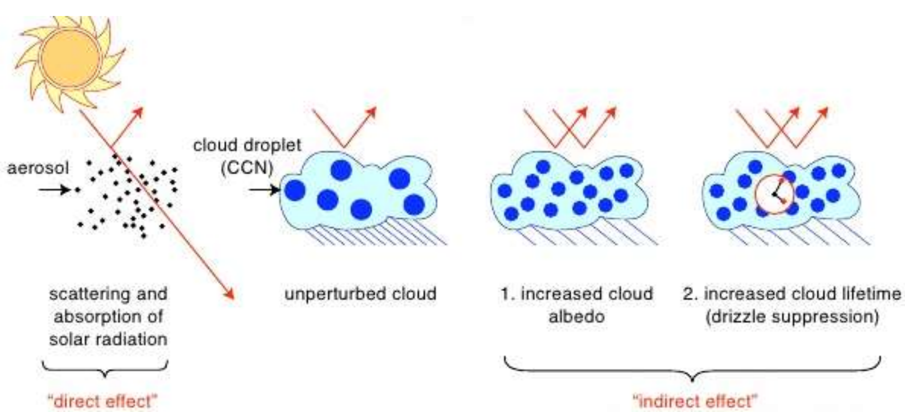


Fig.1 Scattering of sunlight by atmospheric aerosols.

Why do we care about Aerosols?

We care about aerosols because it tend to cause cooling of the Earth's surface immediately below them. This cooling occur due to that most aerosols reflect sunlight back into space, they have a "**direct**" cooling effect by reducing the amount of solar radiation that reaches the surface. The magnitude of this cooling effect depends on the size and composition of the aerosol particles, as well as the reflective properties of the underlying surface. It is thought that aerosol cooling may partially offset expected global warming that is attributed to increase in the amount of carbon dioxide from human activity [3, 6] .

Theoretical Part: Equations

The method followed in our work was to measure the aerosols in direct sunlight. The basic concept is to determine how light intensity differs from out space to when it enters earth's atmosphere. To describe that mathematically, we use Beer's law[7] :

$$I = I_0\, e^{-am} \qquad (1)$$

Where, $\boldsymbol{I}$ is the intensity of sunlight that we measure, $\boldsymbol{I_0}$ is the intensity of sunlight through space, $\boldsymbol{a}$ is the total atmosphere optical thickness and, $\boldsymbol{m}$ is air mass* which is approximately equal to $\frac{\mathbf{1}}{\boldsymbol{sin\theta}}$, where $\boldsymbol{\theta}$ is altitude sun angle. The total atmosphere optical thickness (a) is equal to:

$$a = a_a + a_R \frac{P}{P_0} \qquad (2)$$

**Air mass: the ratio between the path length that sunlight takes through atmosphere to the shortest path can be taken i.e. when sun is directly overhead. (dimensionless) [8]*

Where $a_a$is the *aerosols optical thickness* (AOT) that will be measured and a_R is Rayleigh scattering which is multiplied by the ratio between atmospheric pressure at the location of measurements (P) to the standard sea level atmospheric pressure (P_0) which is equal to 1013.25 millibar. To simplify the equation, we assume that $P_0 = P$ since we measured in a place close to the sea level. Rayleigh scattering a_R is a function of wavelength(λ) as shown:

$$a_R = 0.008569\lambda^{-4}(1+0.0113\lambda^{-2}+0.0013\lambda^{-4}) \qquad (3)$$

By substituting with (λ) = 0.520 millimeter (the green light wavelength of the green filter that we used in the device) then we obtain $a_R = 0.122303$

Thus,

$$a = a_a + a_R \qquad (4)$$

As we have stated previously, that the principle of the device is convert sunlight to voltage, and the voltage is proportional to the detected intensity we can write Beer's law as:

$$V = V_0 \left(\frac{r}{r_0}\right) e^{-am} \qquad (5)$$

Where ***r*** is the distance between the earth and the sun measured in astronomical unit (AU), $\boldsymbol{r_o}$ is average distance between the earth and the sun. This distance vary through the year due to the oval orbit of the earth around the sun. Approximately, we can assume the ratio$(\frac{r}{r_0})$ equals unity.

Substituting eq.(4) into eq.(5), we find that

$$V = V_0 e^{-(a_a+a_R)m}$$

Taking the logarithm for both sides:

$$lnV = lnV_0 - a_0 m - a_R m$$

Solving for a_0 we get:

$$a_0 = \frac{1}{m}(lnV_0 - lnV - a_R m)$$

$$a_0 = \frac{1}{m}(\ln(\frac{V_0}{V}) - a_R m)$$

We replaced V_0 by extraterrestrial constant (ET) which can be calculated from the calibration and indicates how our device can measure the intensity if it place in out space. As well we replaced V by the difference between the signal voltage (V_s) and the dark voltage (V_d) to obtain an expression for the *aerosol optical thickness* (**AOT**)

Now we can write the *aerosol optical thickness* in a mathematical formula:

$$\text{AOT} = \frac{1}{m}(ln\frac{ET}{V_s - V_d} - 0.122303m)$$

AOT can be expressed in term of the percentage of light that is transmitted through the atmosphere, according to this formula [4]:

$$\text{Transmission (\%)} = 100 \times e^{-a}$$

Materials

- Arduino board
- Light dependent resistor (LDR)
- Resistor (540 Ω)
- Hookup wires
- Breadboard
- Monochromatic filter (Green ~ 520 nm)
- USB cable
- Laptop
- Arduino program (IDE)

Practical Part: Circuits

The first circuit we used was the same as that used by the previous group[4] in which the LED photometer was the active components. Such circuit has three main components: a green LED, an operational amplifier (741 op amp) to amplify the sunlight signal falling on the LED and convert it to a measurable voltage, and a resistor shown in Fig.2. However, in order to get a more functional device and better measurements we wanted to use an Arduino, a developed integrated circuit, instead of the digital multimeter.

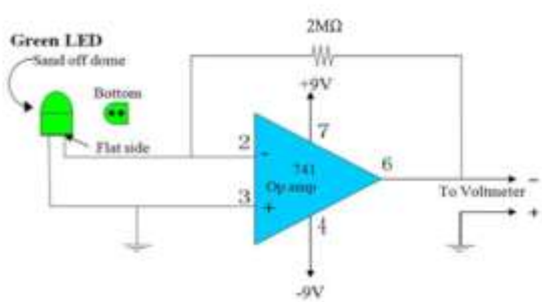


Fig.2 LED Photometer circuit.

Arduino is basically a microcontroller with complementary components that facilitate programming and incorporation into other circuits. We used the Uno version (1.0) of Arduino. It has an operating voltage of 5 V and it can powered by the USB connection to a laptop which is the power source in our device and programmed (Arduino C language) with a software on the computer. [9]

Three circuits were contributed with the Arduino to get the best circuit for the device:

Circuit 1 :

- Green LED with amplifier

  It was impossible to connect our previous circuit device with Arduino since the voltage for 741 op amp is bipolar and the Arduino is only with one positive port. This step was avoided to prevent damage to the microcontroller. [10]

Circuit 2 :

- Light sensor Module

We added a light sensor module which works as an LDR and an amplifier and has an adjusting potentiometer. This component works as a switch, OFF when LDR resistance exceeds the resistance value of the potentiometer and ON when LDR resistance being less so, it wasn't convenient for measuring light intensity.[11]

Circuit ❸ :

- LDR Circuits

Light-dependent resistor (LDR) or photocell is a resistor change its resistance value depending on the amount of light fall onto its face. LDR is small, inexpensive, low-power, easy to use and don't wear out.[11]

Connecting a photo-resister (LDR) to the analog input of the microcontroller, one end to power and one to a pulldown resistor to ground. The high intensity lower the resistance of the LDR leading to an increase to the current flow.[11] However this component was sensitive to high temperatures which lead to illogical readings. To avoid the

thermal effect we chose the least affected type of LDR which is cadmium sulfide (CdS). As shown in the figure below, its maximum peak of detecting is in the visible range. [12]

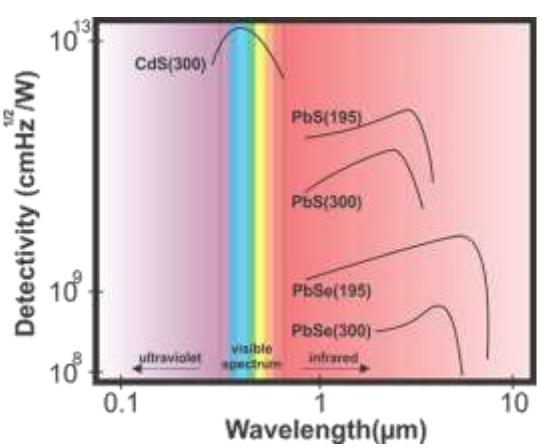


Fig.2 Relation between wavelength and detection of LDR types

To make this circuit provides a linear voltage with respect to brightness, we had to compute the proper resistance needed by this given low.[13]

$$R = \sqrt{(R_{dark}) * (R_{brightness})}$$

Thus, the circuit was the proper one for our device providing logical readings for our measurement.

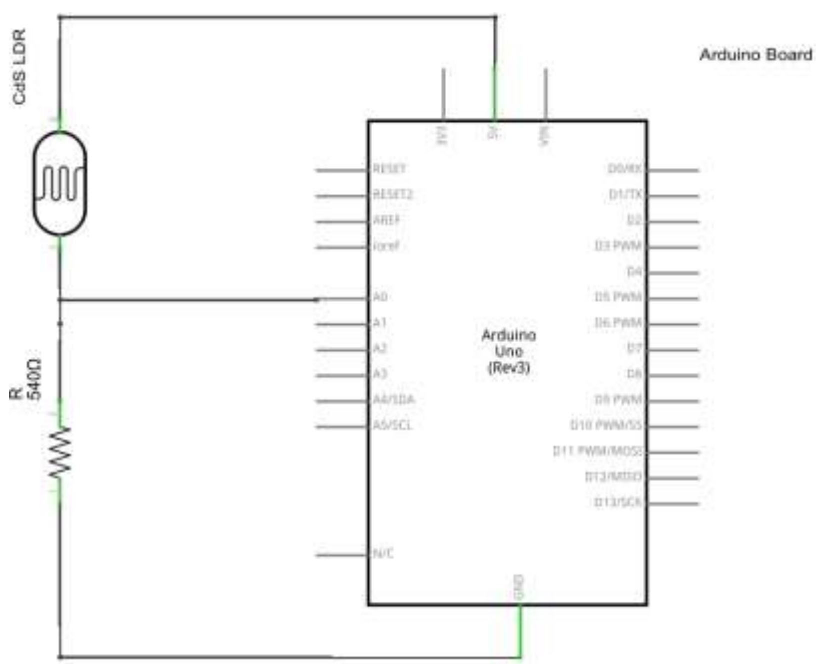


Fig.3 Scheme of LDR Circuit

Calibration

The first step before taking the measurements is to do the calibration for the device to calculate the constant (ET). The calibration should done for a long time interval and take many voltage readings, sun angle using online calculator[8] * then, calculate the air mass. Then, drew the relationship between air mass and lnV to get straight line where the y-intercept represents the value of $lnET$.

In this project, we calibrated our device in two separate days: 28 April 2015 and 13 May 2015 at same location (KAU). (See tables 1, 2. appendix II)

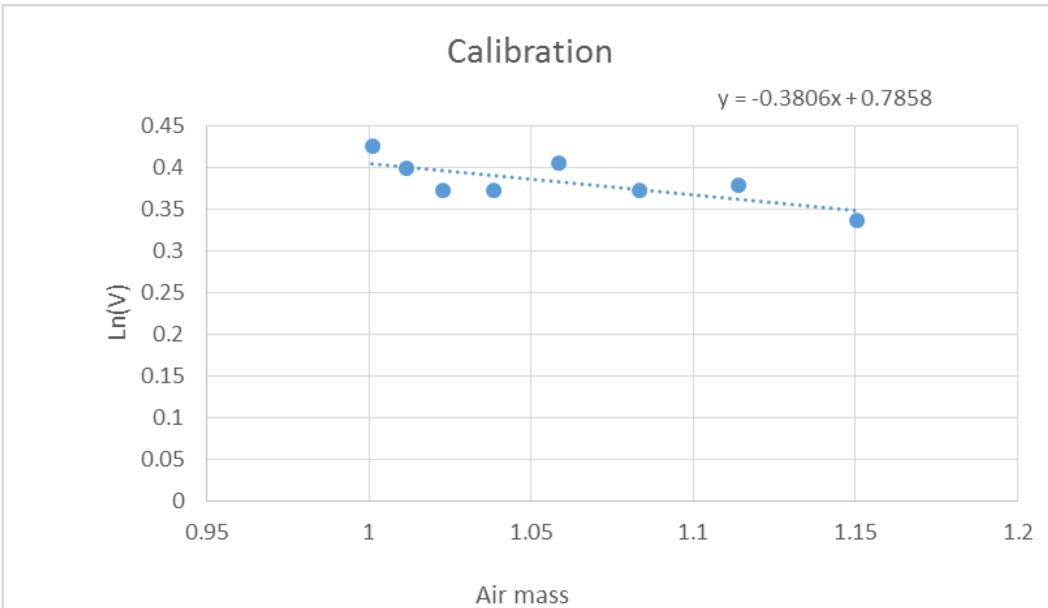


Fig. 4 Calibration of our device

We then took the average for ET, which was= 3.4

*Online calculator gives the sun angle through the day according to location and time. For Jeddah: $Latitude = 21°42', Longitude = 39°10$ $and\ time\ zon =$ 3)

Results & Discussion:

i. 2015

The measurements of aerosols optical thickness were taken at King Abdul-Aziz University (KAU) for two days in a row at almost 11:00 p.m.

Day	AOT_{avg}
Monday 18 May 2015	0.62
Tuesday 19 May 2015	0.58

(See appendix II for table data)

ii. 2009-2010

From pervious study that had done by another students team for three months in 2009 – 2010, The AOT values that measured in King Abdul-Aziz University are shown below: [4]

[4]

Day	AOT_{avg}
16 Nov 2009	0.58
14 Dec 2009	0.32
28 Dec 2009	0.32
11 Jan 2010	0.21
25 Jan 2010	0.12

iii. AOT in other regions of Saudi Arabia

A wide study of aerosols had been published in December 2014 by Farahat et al [1]. The study was done using multi sensor approach and covered four regions of Saudi Arabia from 2003 till 2013. It showed unregulated variation of aerosols optical thickness values through measurements period as shown below for average AOT for wavelength ~ 550 nm:

	Region	$\boldsymbol{AOT_{550}}$
1	Tabuk	0.25
2	Mecca	0.39
3	Dhahran	0.52
4	Rub Al Khali	0.27

By looking to the aerosols optical thickness (AOT) values that measured at King Abdul-Aziz University in 2009 [3] and those of 2015, we find that the values increased. However, we can't consider our current readings as a precise figures. The accuracy of Arduino device cannot be resolved due the short period of time that measurements have been taking. Studying of aerosols requires a long period that lies up to months or years. Beside, our measurements were taken in one month while it is well known that aerosols varies from month to month and from region to another.

Conclusion

We managed to get good measurements using Ardiuno which makes the addition of this microcontroller is an excellent idea to obtain the required results of the aerosols optical thickness (AOT).

For further work, we suggest that this device can be more valuable by adding extra hardware. Our first suggest is to replace the laptop and USB cable by LCD screen and Bluetooth or WiFi shield to send data to the computer. That will make the device totally portable and easy to use. Other component can be benefit for measuring is the accelerometer [14] which can gives the sun angle automatically. Another suggestion is to use a servo motors for solar tracking technique to follow the sun along the whole day without manual trigger.

References

1. Farahat, A., H. El-Askary, and A. Al-Shaibani, *Study of Aerosols' Characteristics and Dynamics over the Kingdom of Saudi Arabia Using a Multisensor Approach Combined with Ground Observations.* Advances in Meteorology, 2014.

2. Guenther, A. *The importance of aerosol research*. 2013; Available from: http://phys.org/news/2013-12-importance-aerosol-qa-alex-guenther.html.

3. Voiland, A. *Aerosols: Tiny Particles, Big Impact*. Earth Observatory 2010; Available from: http://earthobservatory.nasa.gov/Features/Aerosols/.

4. Basma Sindi, Rash Sayqal, and H. Aljawhari, *Monitoring Atmospheric Aerosols Using Green (LED)*, 2010.

5. Physics, H.; Available from: http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html.

6. *Aerosols: Climate and Air Quality*. U.S. Department of Commerce, National Oceanic & Atmospheric Administration Available from: http://www.esrl.noaa.gov/research/themes/aerosols/.

7. DuBois, D., *Measurement of Aerosol Optical Thickness*

Using a Narrow Band Sun Photometer, in *Atmospheric Measurements*1998: University of Nevada.

8. *Terrestial Solar Radiation.* Available from: http://www.pveducation.org/pvcdrom/properties-of-sunlight/air-mass.

9. Abdullah, A.A., *Simply Arduino*.

10. Room, T.v. *Operational Amplifier*. 2011; Available from: http://www.sentex.ca/~mec1995/gadgets/741/741.html.

11. *Photocells*. 2015; Available from: https://learn.adafruit.com/photocells/using-a-photocell.

12. 2015; Available from: http://www.resistorguide.com/photoresistor/.

13. Arduino. *Chosing a pull down resistor for an LDR: Axel Benz formula*. 2014; Available from: https://arduinodiy.wordpress.com/2014/07/07/chosing-a-pull-down-resistor-for-an-ldr-axel-benz-formula/.

14. AMIRSAB. *Accelerometer, Arduino and Processing*. Physical Computing 2010; Available from: https://chalmersphyscomp10.wordpress.com/2010/09/17/mma7260q/.

Appendix I

Program Code written by Arduino C

```
//define variable
int SensorPin = A0;
int SensorReading;
int Voltage;


void setup(void)
  // serial.begin command to connect with PC
 { Serial.begin (9600) ; }


void loop(void)
{

  SensorReading = analogRead(SensorPin);
  Serial.print("  ");
  float Voltage = (float(SensorReading) * (5.0 / 1023.0));
```

```
Serial.print(Voltage);
Serial.print("  ");
Serial.println(SensorPin, DEC);
//show decimals in serial monitor
    delay(5000L);

}
```

Appendix II

Table 1

Calibration data of 28 April 2015

Time	Voltage	Sun angle	Ln (V)	Air mass
0.427083333	3.49	59.08	1.249902	1.1656566
0.4375	3.48	62.53	1.247032	1.1270749
0.447916667	3.53	65.96	1.261298	1.0949769
0.458333333	3.57	69.35	1.272566	1.0686591
0.46875	3.57	72.66	1.272566	1.0476108
0.479166667	3.6	75.85	1.280934	1.0312903
0.489583333	3.6	78.8	1.280934	1.0194146
0.5	3.6	81.28	1.280934	1.0116944

Table 2

Calibration data of 13 May 2015

Time	Voltage	Ln(V)	Sun angle	Air mass
10:15	1.4	0.336472	60.4	1.150442
10:30	1.46	0.378436	63.9	1.11386
10:45	1.45	0.371564	67.4	1.083446
11:00	1.5	0.405465	70.9	1.058488
11:15	1.45	0.371564	74.4	1.038437
11:30	1.45	0.371564	77.9	1.022873
11:45	1.49	0.398776	81.3	1.011752
12:20	1.53	0.425268	87.3	1.001148

Table 3

Measurements of Monday 18-May-15

Time	V	Sun Angle	Air mass	AOT
10:55	1.61	69.9	1.06509711	0.578168
11	1.51	71.1	1.057215	0.644044
11:05	1.47	72.3	1.049905371	0.674951

Table 4

Measurements of Tuesday 19-May-15

Time	V	Sun Angle	Air mass	AOT
11:00	1.54	71.13	1.057025361	0.625571
11:05	1.57	72.3	1.049905371	0.612267
11:10	1.72	73.5	1.043150083	0.52955