# **Determination of aerosol optical depth using a Micro Total Ozone Spectrometer II (MICROTOPS II) sun-photometer**

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## Abstract

Aerosols affect climate and climate change by absorbing and scattering incoming solar radiation. These effects are quantified by the aerosol optical depth (AOD), which is a measure of the reduction in solar radiation due to the presence of aerosols. We performed retrievals of AOD during an Intensive Observational Period (IOP) at Brookhaven National Laboratory (BNL), USA, located at 40.86° N, -72.87° W, from July 15 through August 15, 2011, using a Micro Total Ozone Spectrometer II (MICROTOPS II). This instrument provides fully automatic measurements of direct solar irradiance and retrievals of AOD at four wavelengths near 340, 500, 870, and 1040 nm. The calibration of the instrument to measure AOD at multiple wavelengths is based on a Langley analysis, in which the logarithm of the intensity of the direct solar radiation at a given wavelength is plotted against the inverse of the cosine of the angle between the sun and the vertical. The negative slope of the line is the total optical depth. The optical depth due to Rayleigh scattering as well as those due to ozone and nitrogen dioxide absorption are subtracted to obtain the AOD. The main goal of this experiment was to determine the aerosol optical depth over several days at multiple wavelengths. Our results show that the AOD varies considerable from day to day, ranging from 0.16 to 1.99, 0.11 to 1.69, 0.04 to 1.72, 0.05 to 2.16, with wavelengths 340, 500, 870, and 1020 nm, respectively. In addition, AOD depends on wavelength, increasing as the wavelength decreases.

## Introduction

An aerosol is a suspension of solid or liquid particles in air, with diameters ranging from a few nanometers to several tens of micrometers. Aerosols have various sources from both natural and anthropogenic processes. Natural emissions include wind-blown mineral dust and aerosols from volcanic eruptions, natural wild fires, vegetation, and oceans. Anthropogenic sources include emission from fossil fuel and biofuel combustion, industrial processes, agriculture practices, and human-induced biomass burning [Chin and Kahn, 2009]. Aerosols affect climate and climate change by absorbing and scattering incoming solar radiation. These effects are quantified by aerosol optical depth (AOD). Routine observation of aerosol optical depth is a fundamental way of determining aerosol optical characteristics and their influence on the global radiation budget and on climate change. The primary focus of research during this intensive observational period is to determine the AODs over several days at multiple wavelengths, using a MICROTOPS II 5 Channel Sun-photometer [Porter et al., 2001].

## Instrument Description and Operation

The MICROTOPS II Sunphotometer is a portable instrument, measuring 10 cm by 20 cm by 4.3 cm, and weighing only 600grams [Morys et al., 2001]. A sun-target and pointing assembly is permanently attached to the optical block and laser-aligned to ensure accurate alignment with the optical channels. When the image of the sun is centered in the bull's-eye of the sun target, all optical channels are oriented directly at the solar disk [MICROTOPS II User's Guide].

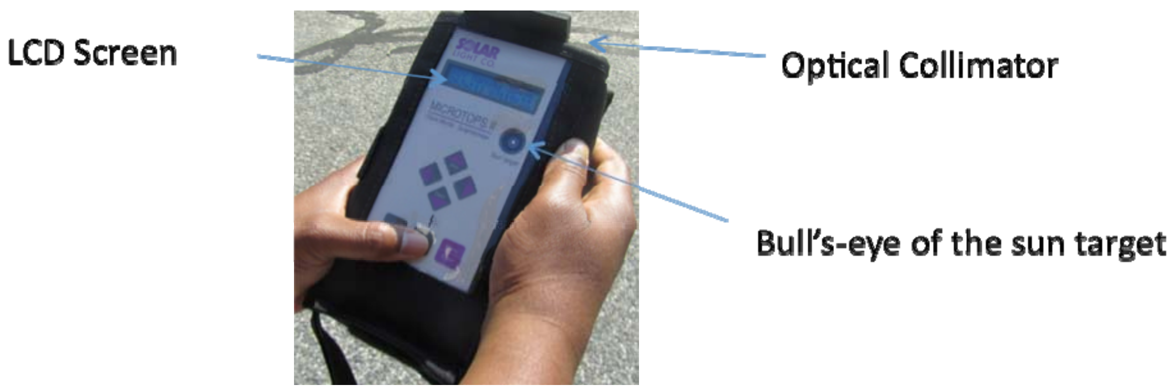



**Fig. 1** MICROTOPS II Sunphotometer

The physical and operational characteristics of the instrument are detailed in the "User's Guide", which is publicly accessible on the Internet (http://www.solar.com/manuals.htm). Microtops II measurements are conducted on days that are cloud-free as possible, in order to avoid cloud contamination. The Sunphotometer measures solar radiance, from which it automatically derives AOD, in five spectral wavelength bands. The five wavelengths may be specified while ordering the instrument such that appropriate filters are custom designed and installed by the manufacturer. In this study, the MICROTOPS II Sunphometer with a serial number16313 has five wavelengths: 340, 500, 870, 936, and 1020 nm. Since radiation at 936nm is highly absorbed by water vapor, discussion of results from this channel is not included in this paper. The filters used in all channels have a peak wavelength precision of ±1.5 nm and a full width at half maximum (FWHM) of 10 nm (http://www.solar.com/sunphoto.htm).

## Method

The manufacturer-supplied default MICROTOPS II protocol is to collect 32 samples (over a period of 10 seconds) for each measurement, and to save the average of the 4 top voltages to the data file. The AOD is derived based on Beer-Lambert-Law as follows:

$$\frac{I}{I_0} = e^{-m\tau_{tot}} \qquad (1)$$

I= Measured Solar Irradiance

$I_0$= Solar Irradiance on top of the atmosphere

m = Airmass (1/cos (zenith angle))

$\tau_{tot}$= Total Optical Depth

The total optical depth at each wavelength is obtained by taking the natural logarithm of equation (1), which is shown below:

$$\tau_{tot} = \frac{\ln(I_0) - \ln(I)}{m} \qquad (2)$$

where the total optical depth is comprised of contributions from aerosol, Rayleigh scattering, ozone, and nitrogen dioxide,

$$\tau_{tot}(\lambda) = \tau_{aer}(\lambda) + \tau_{Ray}(\lambda) + \tau_{O_3}(\lambda) + \tau_{NO_2}(\lambda) \qquad (3)$$

Substraction of Rayleigh, ozone, and nitrogen dioxide optical depths from the total optical depth yields the AOD. In our case, Rayleigh correction is done automatically, according to the calibration of the manufacturer of MICROTOPS II Sunphotometer.

$$\tau_{aer}(\lambda) = \tau_{tot}(\lambda) - \tau_{Ray}(\lambda) - \tau_{O_3}(\lambda) - \tau_{NO_2}(\lambda) \tag{4}$$

where

$\tau_{aer}$ = Aerosol Optical Depth

$\tau_{Ray}$ = Rayleigh Optical Depth

$\tau_{O_3}$ = Ozone Optical Depth

$\tau_{NO_2}$ = Nitrogen Dioxide Optical Depth

We used the following formulas to calculate $\tau_{O_3}$ and $\tau_{NO_2}$ in the table 1

$\tau_{O_3}$= $O_3$ column abundance in Dobson units (DU) × $O_3$ absorption coefficient [http://daac.ornl.gov/FIFE/Datasets/Optical_Properties/optical_thick_staff.html. In our analysis we have used an average value of 325 DU for ozone column burden and an average value of $8\times10^{15}$ molecules per $cm^2$ for the column burden of nitrogen dioxide. These values were obtained from OMI satellite, available at http://ozoneaq.gsfc.nasa.gov. Ozone and nitrogen dioxide absorption coeffiecients were taken from http://ceancolor.gsfc.nasa.gov/REPROCESSING/R2009/sources.

$$\tau_{NO_2} = NO_2 \text{ column burden (molec/cm}^2) \times NO_2 \text{ absorption coefficient} \tag{5}$$

The Ångström coefficient is calculated using two optical depth measurements, specifically at 500 and 870nm, as

$$\alpha = -\frac{\ln(\tau_{0.5}) - \ln(\tau_{0.87})}{\ln(0.5) - \ln(0.87)} \tag{6}$$

This coefficient is a qualitative measure of the sizes of the particles contributing to the aerosol optical depth, ranging from near zero for particles of diameter much greater than the wavelength to about 2.5 for accumulation mode aerosol particles [Michalsky et al., 2010].

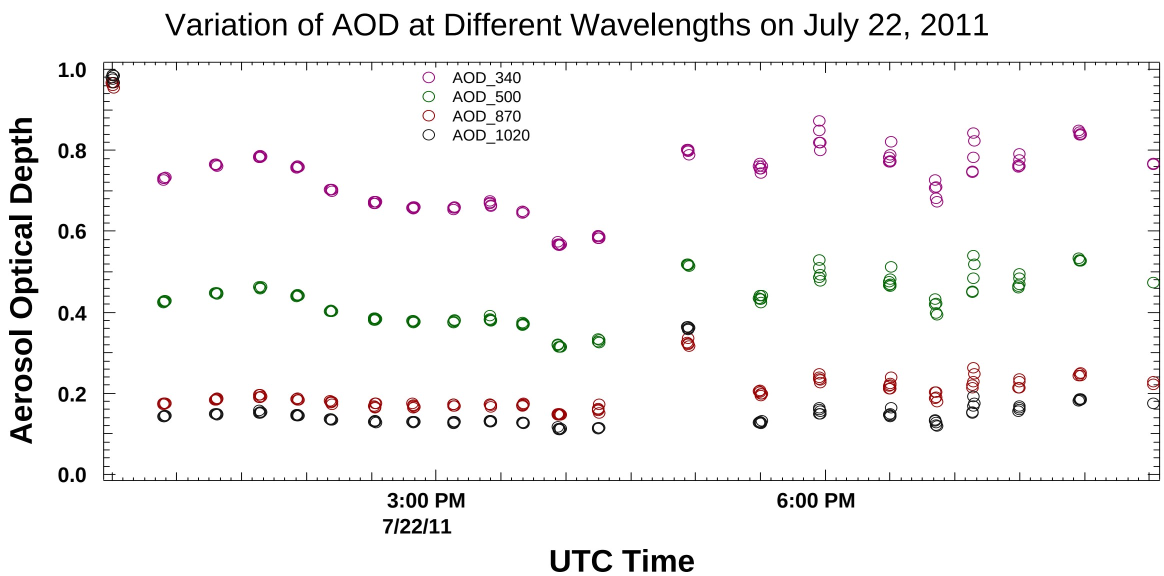
Table 1: Ozone and nitrogen dioxide optical depths for multiple wavelengths.

| $\lambda$ (nm) | $\tau_{O_3}$ | $\tau_{NO_2}$ |
|---|---|---|
| 340 | 0 | 0.0032 |
| 500 | 0.01 | 0.0012 |
| 870 | 0 | 0 |
| 1020 | 0 | 0 |

**Results**

Figure 1and 2 show scatter plots of AOD as a function of time at different wavelengths on 22$^{nd}$ and 27$^{th}$ of July 2011. The AODs on Figure 2 are much higher than the ones on Figure 1. The table below shows AOD variation, at four different wavelengths, on those two days, over a period of 8 hours.

a)




b)

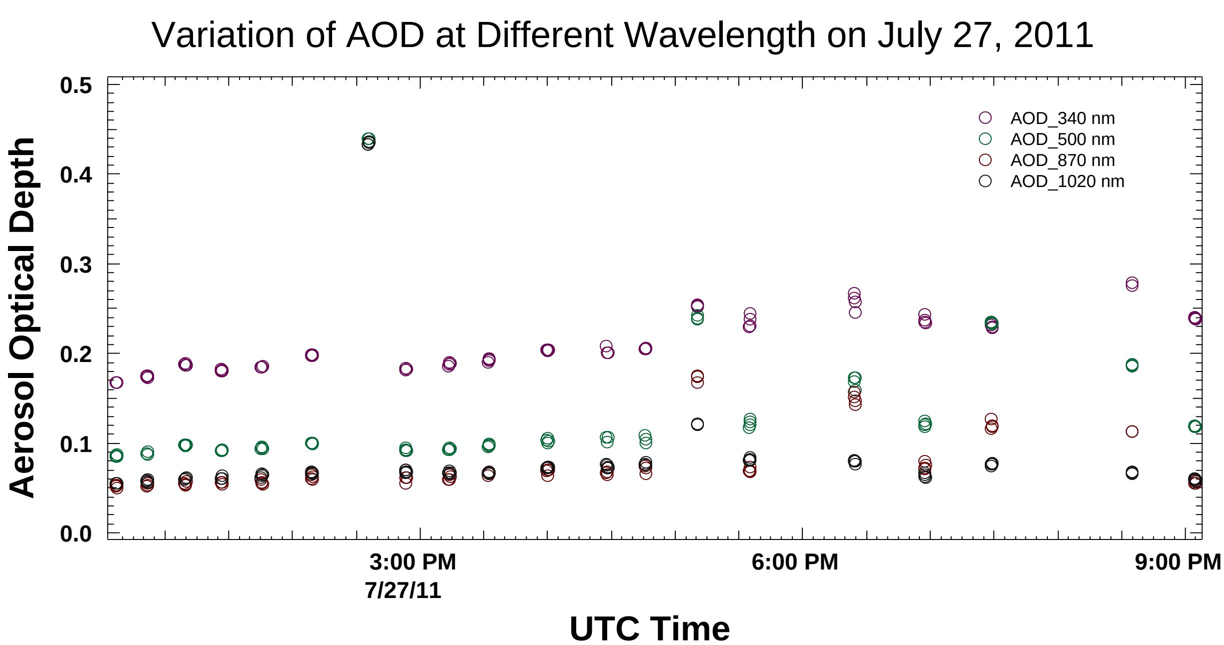



Fig.2. AOD variation with wavelength at BNL on

a) July 22nd, 2011 and b) July 27th, 2011

Table 2 shows that AOD at different wavelengths on the 22nd of July is higher than the one on the 27th of July.

Table 2: Ranges of variation of AOD for multiple wavelengths

| Wavelengths (nm) | AOD variation on July 22, 2011 | AOD variation on July 27, 20011 |
|---|---|---|
| 340 | 0.60 – 0.90 | 0.16 – 0.30 |
| 500 | 0.30 – 0.50 | 0.08 – 0.24 |
| 870 | 0.20 – 0.25 | 0.05 – 0.15 |
| 1020 | 0.15 – 0.20 | 0.05 – 0.12 |

Figure 3 illustartes AOD as function of wavelength over several days in the month of July 2011. This figure clearly indicates AOD variation with wavelength and exhibits diurnal variability as well as considerable daily variation, ranging from 0.16 to 1.99, 0.11 to 1.69, 0.042 to 1.72, and 0.045 to 2.16, at wavelengths 340, 500, 870, and 1020 nm, respectively. Figure 4 shows the variation of the Ångström coefficient over a period of 13 days, in which daily as well as day-to-day variation is seen.

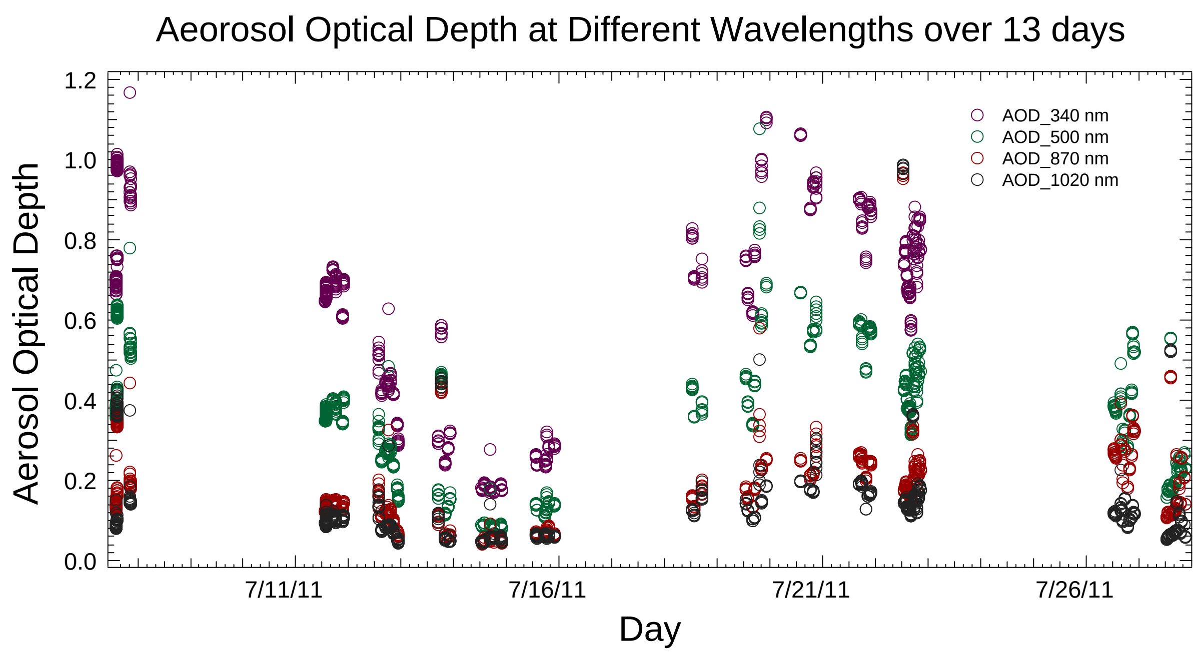



Fig.3 Sunphotometer Microtops II AOD over 2011 summer at BNL

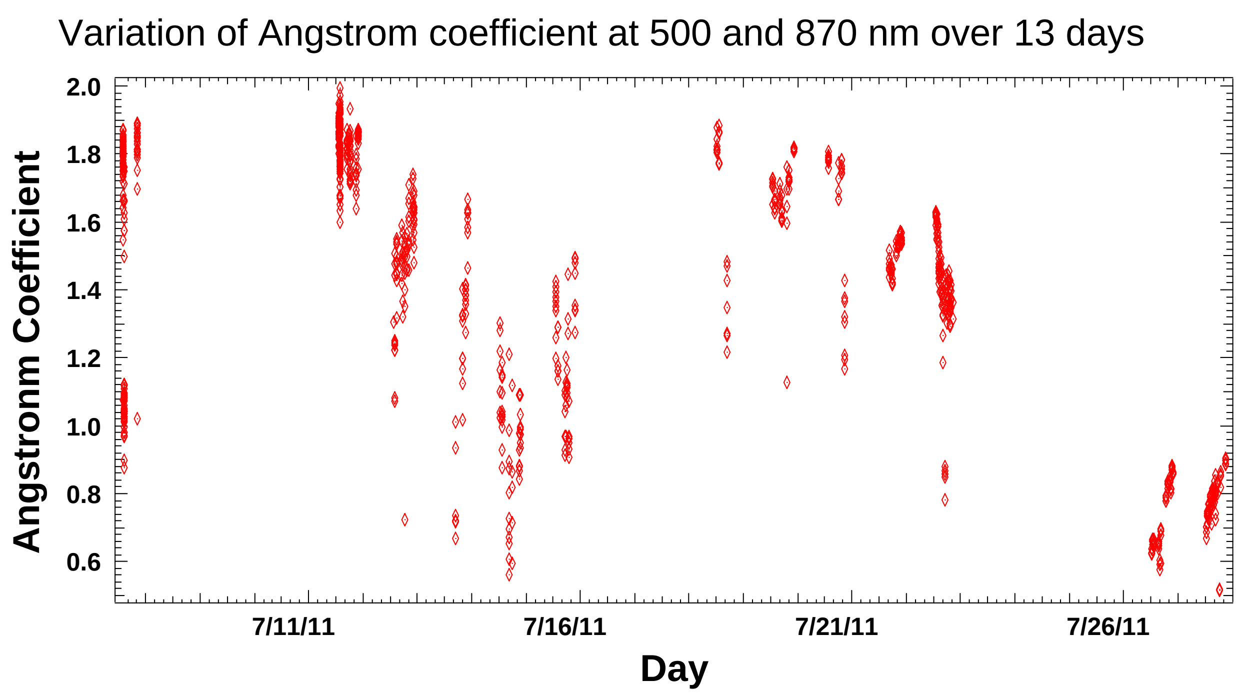



Fig.4 Angstrom coefficient over the 2011 summer at BNL

## Discussion and Conclusion

Our results show that the AOD varies considerable from day to day, ranging from 0.16 to 1.99, 0.11 to 1.69, 0.042 to 1.72, and 0.05 to 2.16, at wavelengths 340, 500, 870, and 1020 nm, respectively. In addition, AOD depends on wavelength, typically increasing as wavelength decreases. The high AOD values and their variability in our data could be due to the presence of clouds or misalignment of the instrument with the sun, as noted by Porter et al. (2001). The MICROTOPS II sunphotometer offers a convenient and inexpensive way to measure aerosol optical depths. Our future plan is to compare the data collected using other sunphotometers with those from our MICROTOPS II data.

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