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Aerosol optical depth computational package for hand-held Sun photometer

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Abstract
This report discuss about the design, functions and applications of aerosol optical depth computational software package for the hand-held Sun photometer. The graphical user interface application software has been developed in-house using Microsoft Visual Basic 2010.NET rapid application development object oriented programming language. The software package is primarily used to compute the aerosol optical depth (AOD) from the measured Sun photometer output voltages as a function of wavelength. It also computes the other parameters required for AOD computation like solar zenith angle, atmospheric airmass, Rayleigh optical depth (scattering by air molecules) and molecular optical depth (absorption by gases). The Rayleigh optical depth can be computed using different computational methods as a function of wavelength. The molecular optical depth is only assumed and estimated for absorption by Ozone. The software is designed and developed for maximum six optical channels. The details about the computational method of atmospheric airmass, Rayleigh optical depth, Ozone optical depth and aerosol optical depth are presented in this note.

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Contents

1. Aerosol optical depth

Atmospheric aerosols are tiny solid and/or liquid particles suspended in the atmosphere and have radius ranging from 0.001 to 100 μm. Aerosols of different sizes, magnitude and composition are produced by the natural or anthropogenic sources and can be transported to different regions depending upon the meteorological conditions. Aerosols vary considerably in shape, size, concentration and composition because of variations in the strength and nature of local sources, variations in the dilution capacity of the air, scavenging processes background burden of particles, etc. Aerosols have the potential to significantly influence our planet through their role in heterogeneous chemistry, as well as their effect on the Earth's climate as they scatter and absorb visible incoming solar radiation and outgoing terrestrial radiation and serve as condensation nuclei for cloud droplet formation [12].

Aerosol optical depth (AOD) is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between the point of observation and the top of the atmosphere. AOD is a dimensionless quantity which is related to the amount of aerosol (e.g., urban haze, smoke particles, desert dust, sea salt) distributed within a column of atmosphere over the observation location. It depends upon the amount, size distribution and chemical composition of aerosols. Typically, AOD values of 0.02, 0.2, 0.4, 0.5 and 1.5 corresponds to very clean isolated area, fairly clean urban area, somewhat polluted urban area, fairly polluted area and heavy biomass burning or dust storm event respectively. Increased optical depth reduces visibility and photosynthetic radiation and which in turn alters the Earth's radiation balance. It is a useful parameter needed in various applications such as radiative transfer calculations, estimating visibility, providing atmospheric correction in remote sensing satellite data, air quality, atmospheric turbidity, etc. It is one of the key aerosol optical property and an important input to climate modeling studies [12].

2. Sun photometer

Sun photometer provides a simple and effective means to study aerosols. It is an instrument used to measure the direct beam intensity of sunlight in order to measure the column aerosol loading. As the aerosol loading increases, more light is scattered out of the direct solar beam and the sun photometer

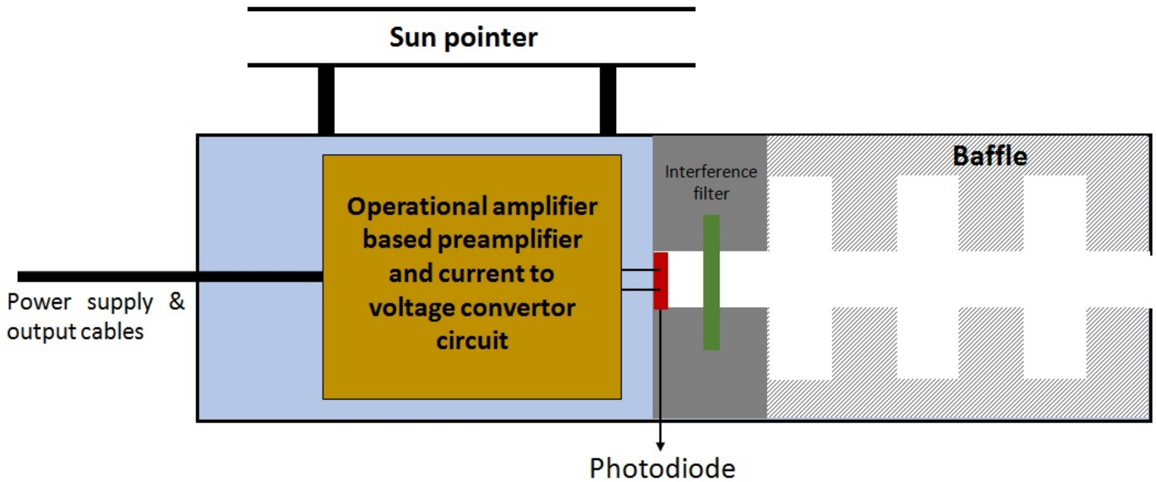

Figure 1. Schematic of PRL built hand-held Sun photometer

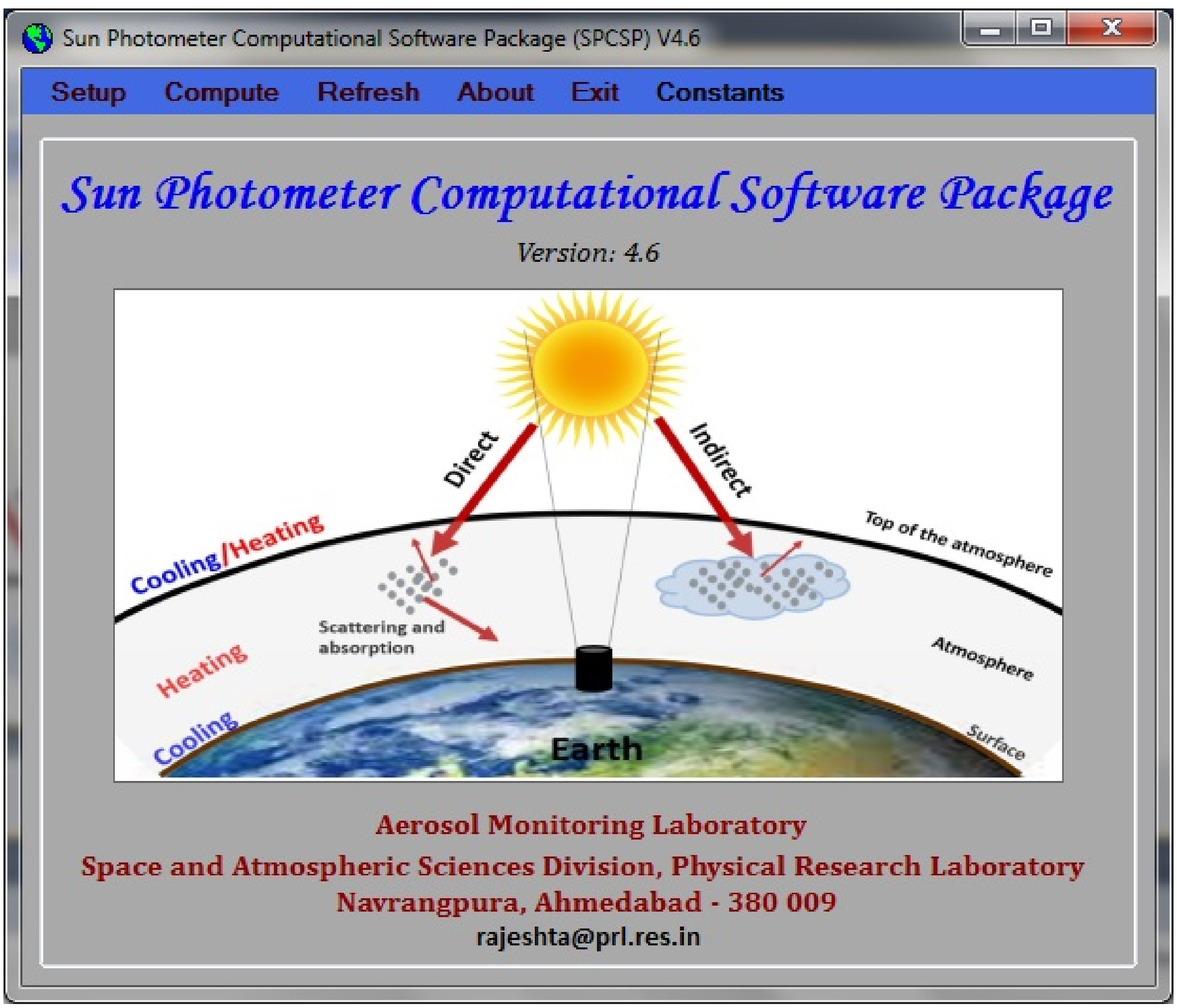

Figure 2. Aerosol optical depth computational software package

measurement decreases. Sun photometry technique uses the Sun as the source, and it measures the intensity of solar radiation while traversing through the Earth's atmosphere. It consists of a narrow field of view sensor which is pointed at the Sun, optical interference filter, and data acquisition or readout system. The spectral band pass of the interference filters is typically 10 nm full width at half maximum (FWHM). By incorporating desired filters, it is possible to make the measurements at desired wavelengths and from these measurements, the columnar aerosol optical depth (AOD) of the atmosphere at the selected wavelengths can be estimated [10,16].

The schematic of the PRL built hand-held Sun photometer is shown in Figure 1. The hand-held Sun photometer consists of (a) baffle in front of photo detector in order to reduce diffuse radiation reaching the detector by reducing the field of view (FOV) of Sun photometer (4^o) (b) interference filter of known narrow pass band wavelength (c) a silicon photodiode is used as detector in order to measure the solar radiation through the interference filter (d) an operational amplifier (CA3140) based circuit is used for pre-amplification cum current to voltage conversion and (e) Sun pointer is used to target towards the Sun during observation. The silicon photodiode is well suited for light detection because its spectral characteristics response typically lies in the range between 350 and 1100 nm.

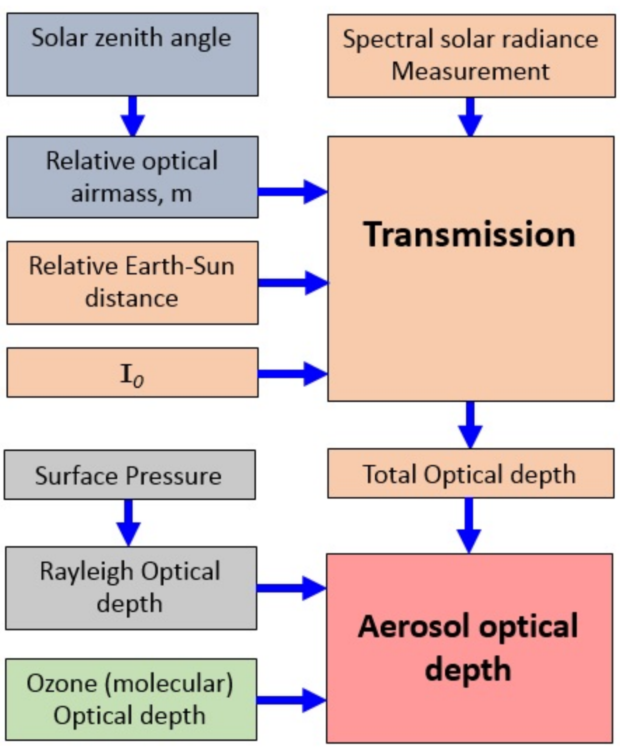

Figure 3. Schematic for the computation of aerosol optical depth

3. Computation of Aerosol optical depth

Aerosol optical depth (AOD) is derived from atmospheric extinction of solar irradiance. Figure 3 illustrates the schematic for the computation of aerosol optical depth. The Sun photometer output is proportional to the spectral irradiance (I) reaching the instrument at the Earth's surface. The total optical depth (τ) can be obtained using the following equation according to Beer-Lambert-Bouguer law [5]:

$$\tau(\lambda) = \frac{-1}{m}\left[ln\frac{I(\lambda)}{I_0(\lambda)} - 2ln\frac{r_0}{r}\right] \quad (1)$$

where τ is total optical depth (including scattering and absorption by aerosol particles and gas molecules), I is the instantaneous solar radiation intensity measured at the Earth's surface and I_0 is the intensity of the solar radiation at the top of the atmosphere. m is the atmospheric airmass, a ratio of path length light beam has actually traveled in the atmosphere to that it would have traveled in vertical direction, and depends upon solar zenith angle (calculated for each latitude, longitude and particular date and time). r and r_0 are mean Sun-Earth distances corresponding to I and I_0. The voltage measured by Sun photometer is proportional to the light intensity arriving at the detector, the Equation 1 can also be expressed as:

$$\tau(\lambda) = \frac{-1}{m}\left[ln\frac{V(\lambda)}{V_0(\lambda)} - 2ln\frac{r_0}{r}\right] \quad (2)$$

where V is the measured voltage on Earth's surface, V_0 is the voltage that Sun photometer would show by measuring solar radiation at the top of the atmosphere and the other variables are the same as Equation 1. The approximate formula to compute atmospheric airmass (m) from solar zenith angle (angle between the zenith and the center of the Sun's disc) that accounts for the effects of refractive index and curvature of the Earth is given by Young (1994) (Equation 3 - 7) [17],

$$y = 1.002432\,Cos^2(\theta) + 0.148386\,Cos(\theta) + 0.0096467 \quad (3)$$

$$z1 = Cos^3(\theta) + 0.149864\,Cos^2(\theta) \quad (4)$$

$$z2 = 0.0102963\,Cos(\theta) + 0.000303978 \quad (5)$$

$$z = z1 + z2 \quad (6)$$

$$m = \frac{y}{z} \quad (7)$$

where θ is the solar zenith angle at the time of measurement which is calculated from,

$$Cos(\theta) = Cos(\delta)\,Cos(\phi)\,Cos(HA) + Sin(\delta)\,Sin(\phi) \quad (8)$$

where δ is the solar declination (it is the angle between a line from the center of the Earth towards the Sun and the celestial equator), ϕ is latitude of the measurement location and HA is the hour angle (it is the time since the Sun was at local meridian, measured from the observer's meridian westward). The detailed equations regarding the computation of δ, HA and θ are discussed in Appendix 1 [7,8]. Atmospheric airmass computed using above equation is better than 1 % at horizon taking into consideration the changes in meteorological conditions (temperature, pressure). The solar zenith angle (θ) can be computed by astronomical formula from latitude and longitude of the place, date and time of measurements [7,8]. Total optical depth (τ) is the sum of optical depths by aerosol (AOD), scattering by air molecules (Rayleigh optical depth - ROD) and absorption by gases (like Ozone) (molecular absorption optical depth - MOD) at the observational wavelength and is expressed as

$$\tau(\lambda) = AOD(\lambda) + ROD(\lambda) + MOD(\lambda) \tag{9}$$

where AOD is the aerosol optical depth (AOD), ROD is the Rayleigh optical depth and MOD is the molecular absorption optical depth due to Ozone. AOD is obtained by subtracting the Rayleigh optical depth and molecular absorption optical depth from total optical depth.

3.1 Computation of Rayleigh optical depth (ROD)

Different computational techniques are available for the calculation of Rayleigh optical depth (ROD) in the atmosphere, as given by Penndorf (1957) [11], Hansen and Travis (1974) [4], Frohlich and Shaw (1980) [3], Nicolet (1984) [9], Bucholtz (1995) [2], Bodhaine et al (1999) [1], etc. ROD is computed using the scattering cross section per molecule for a given wavelength and composition, and it depends only on the atmospheric pressure at the observational location. An error of 0.1 % in ROD translated into a 10 % error in aerosol optical depth [1]. Hence the ROD should be computed as accurately as possible and is normalized to 1013.25 mb. In the present software package, Rayleigh optical depth can be computed using Hansen and Travis (1974), Frohlich and Shaw (1980), Nicolet (1984) and Bodhaine et al (1999), and the equations are discussed as follows;

1. Hansen and Travis (1974)[4]

$$p(\lambda) = \frac{0.008569}{\lambda^{-4}} \tag{10}$$

$$q(\lambda) = \left[1 + \frac{0.0113}{\lambda^{-2}} + \frac{0.00013}{\lambda^{-4}}\right] \tag{11}$$

$$ROD(\lambda) = p(\lambda) + q(\lambda) \tag{12}$$

2. Frohlich and Shaw (1980)[3]

$$ROD(\lambda) = 0.00838\ \lambda^{-3.916-0.074\,\lambda-\frac{0.05}{\lambda}} \tag{13}$$

3. Nicolet (1984)[9]

Rayleigh optical depth (ROD) is calculated by multiplying average scattering cross section (σ_{rs}) of air molecule with columnar number density (n) of air molecules,

$$ROD(\lambda) = \sigma_{rs}(\lambda)\ n \tag{14}$$

where n is 2.153 * 10^{25} $molecules/cm^2$ for standard atmosphere and σ_{rs} (cm^2) is given as

$$\sigma_{rs}(\lambda) = \frac{4.02 * 10^{-28}}{\lambda^{4+x}} \tag{15}$$

$$x = 0.389\ \lambda + \frac{0.09426}{\lambda} - 0.3228 \tag{16}$$

for λ lies between 0.2 and 0.55 μm

$$x = 0.04 \tag{17}$$

for λ lies between 0.55 and 1.0 μm

4. Bodhaine et al (1999)[1]

$$\sigma_{rs}(\lambda) = \frac{1.0455996 - \frac{341.29061}{\lambda^{-2}} - \frac{0.9023085}{\lambda^2}}{1 + \frac{0.0027059889}{\lambda^{-2}} - \frac{85.968563}{\lambda^2}} \tag{18}$$

$$ROD(\lambda) = \sigma_{rs}(\lambda)\ 10^{-28}\ n \tag{19}$$

and λ is wavelength expressed in μm. All of the above equations used to compute ROD were useful over a limited wavelength range and at limited accuracy. Comparing these various equations shows significant differences, especially in the UV. Nicolet (1984), Rayleigh optical depth computation equation is more accurate over a greater range of the spectrum [1].

3.2 Computation of molecular optical depth (MOD)

Molecular absorption optical depth due to Ozone is computed as

$$MOD(\lambda) = TCO\ (2.69 * 10^{16})\ \sigma_{O_3}(\lambda) \tag{20}$$

where TCO is the total column ozone in Dobson unit (DU) at the observational location and σ_{O_3} is the absorption cross-section of Ozone. The daily average total column Ozone can be obtained from the Ozone Monitoring Instrument (OMI) satellite on board Earth Observing System (EOS) Aura platform at a spatial resolution of 0.25 degree. The OMI daily data product OMTO3e-v003 can be downloaded from http://giovanni.sci.gsfc.nasa.gov. The absorption cross-section of Ozone at 293 - 298 K for 350 - 823 nm (Chappuis band) is listed in Appendix 2 [14].

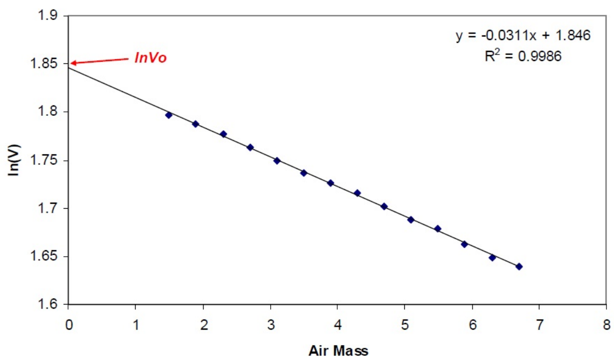

Figure 4. Typical Langley plot and linear fit. The natural log of the detector output voltage, is plotted against the atmospheric mass, m. In clear sky conditions, the resulting curve is a straight line and the fitted straight line is extrapolated to m = 0 to determine the V_0 . The slope of the line is the total optical depth (τ).

V_0 in equation 2 can be computed using Langley plot method [6]. Langley plot is extremely accurate, simple and versatile procedure to provide the I_0 or V_0 of Sun photometers. A Langley calibration is performed by using a Sun photometer to measure the intensity of a narrow spectrum of direct sunlight as the Sun rises (or sets) over the course of a clear morning (or afternoon). In order to obtain the Langley plot calibration, the measurements of V are conducted as a function of the solar zenith angle θ. The Langley plot method assumes that the atmosphere is temporarily invariant and horizontally homogeneous during the period of measurements [6]. The thickness of the atmosphere or airmass (m) between the instrument and the Sun when each measurement is made relative to the thickness of the zenith sky (m =1) is then plotted against the natural log of each measurement. If the atmosphere and its constituents have remained relatively stable over the course of the measurement period, the points will fall along a straight line, as shown in Figure 4. Extrapolation of this line to the intercept (m = 0) yields I_0 or V_0. A good Langley plot depends on having enough variation in the atmospheric airmass while the optical thickness (slope of Equation 2) remains constant. The largest variation of air mass as a function of time happens in the morning or at the end of the day, giving more chances of obtaining a constant atmosphere during the period of measurements. Due to atmospheric refraction, surface albedo, and other issues, the airmass should be limited to angles smaller than 65 or 70 degrees. A good Langley plot also requires a cloud free sky and is usually more accurate in clean days when the atmospheric optical thickness is lower or ideally constant during the period of observations. More accurate Langley plots can be obtained at the top of high mountains in locations with low atmospheric optical thickness. In the present work V_0 values are obtained from the clear sky Sun photometer observations at Gurushikhar, Mt. Abu (1670 m above mean sea level). The Sun photometer measurements on clear days yield values of I_0 or V_0 that are repeatable to within 1%. The extraterrestrial constant V_0 is a number corresponding to each individual instrument and it accounts for all the particularities of that particular instrument including efficiency of the detector, gain of the amplifier, etc. Using Sun photometer for aerosol optical depth determination an absolute calibration is not necessary as long the photometer output voltage is linearly proportional to I. The aerosol optical depth (AOD) is finally computed as

$$AOD(\lambda) = \tau(\lambda) - [ROD(\lambda) + MOD(\lambda)] \tag{21}$$

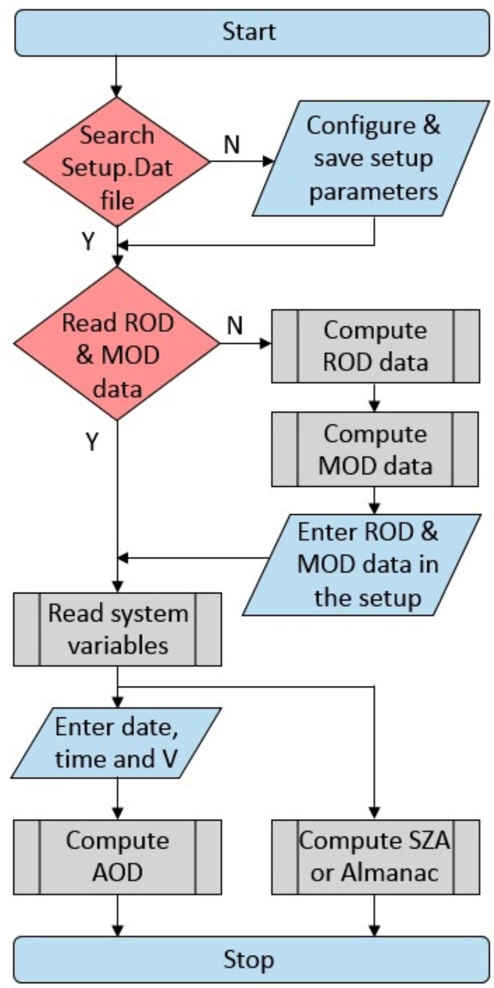

Figure 5. Flowchart of the "Sun photometer computational software package" (SPCSP)

4. Software design, functions and processes

The in-house developed AOD computational package for the hand-held Sun photometer has been written in Microsoft Visual Basic 2010.NET an object-oriented programming language. It is a multi-paradigm, high level programming language, implemented on the .NET Framework which enables

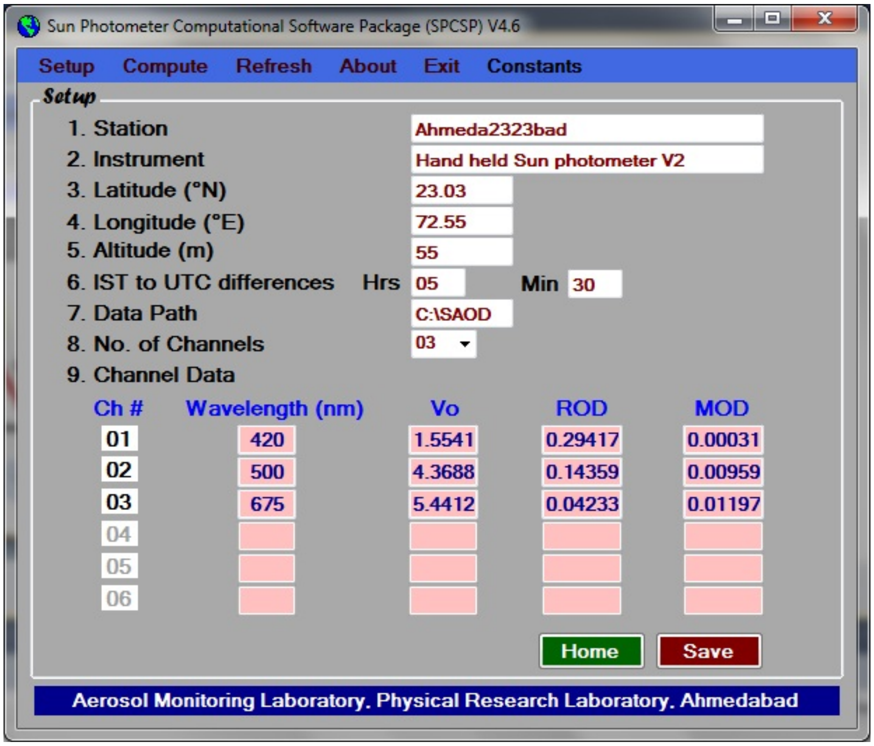

Figure 6. Setup configuration for SPCSP

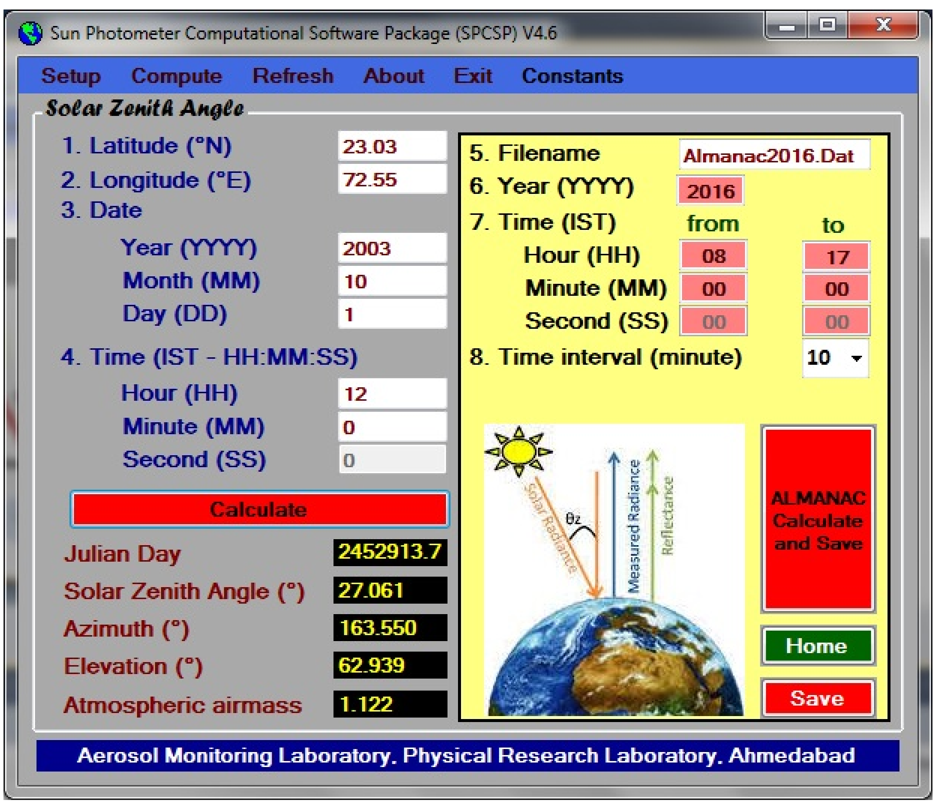

Figure 7. Solar zenith angle and almanac computational graphical user interface

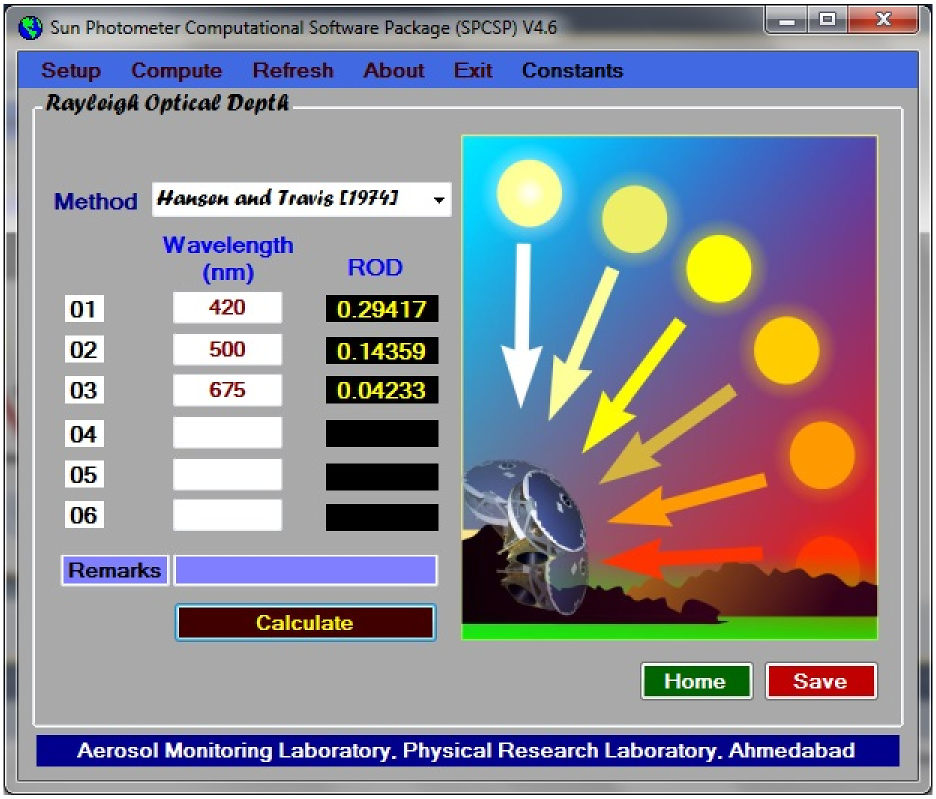

Figure 8. Rayleigh optical depth (ROD) computational graphical user interface

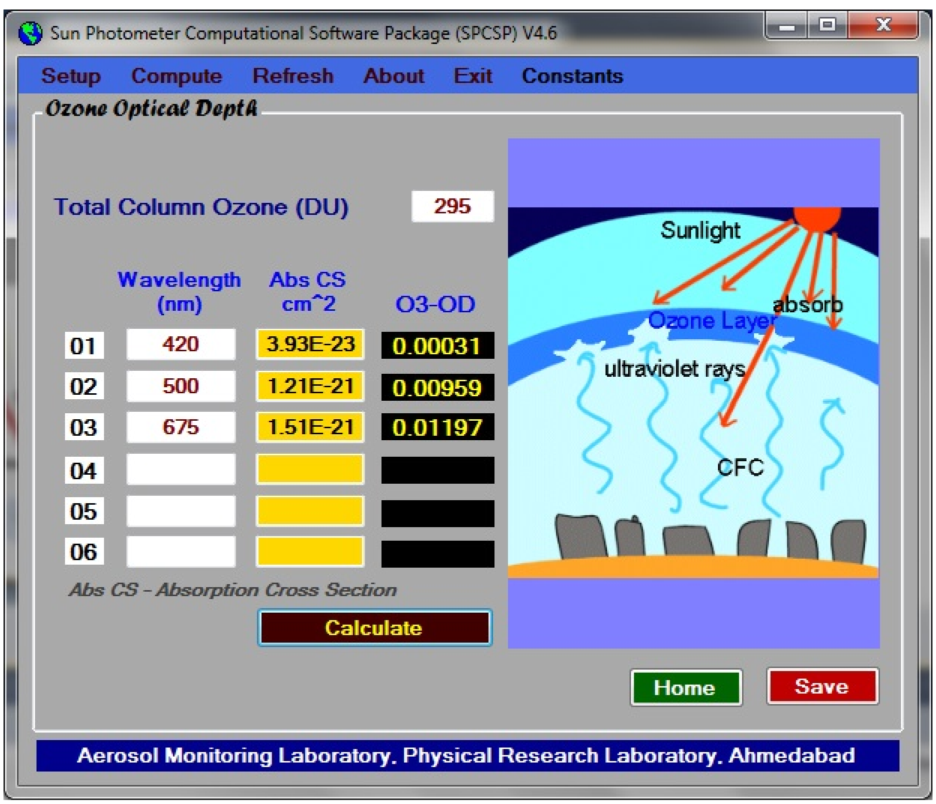

Figure 9. Molecular (ozone) optical depth computational graphical user interface

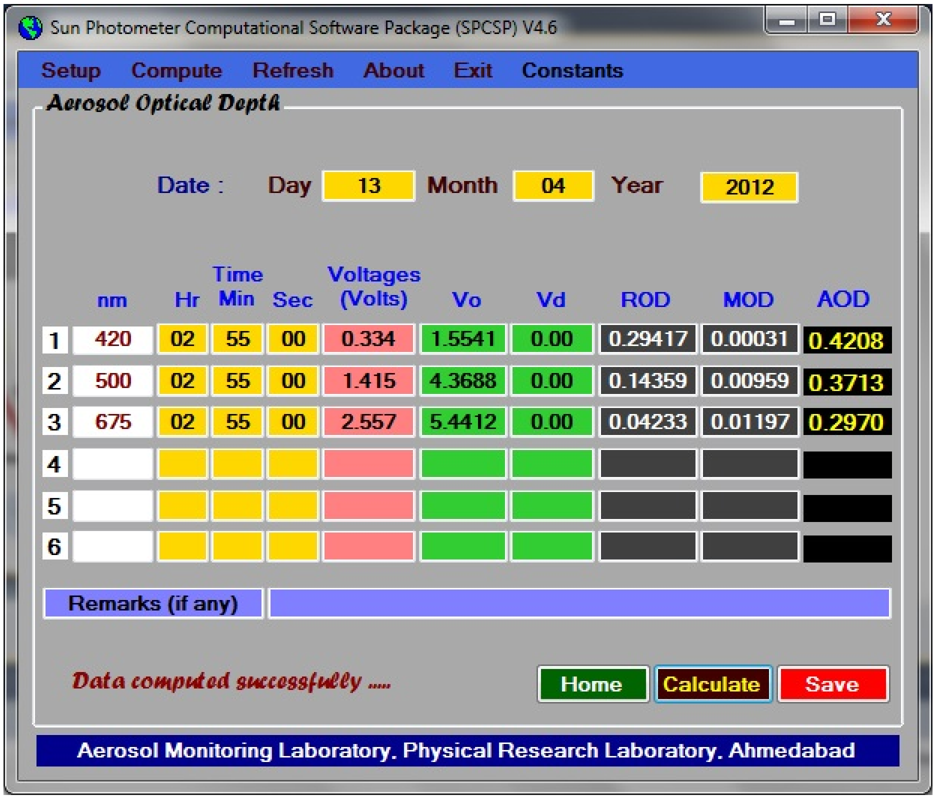

Figure 10. Aerosol optical depth (AOD) computational graphical user interface

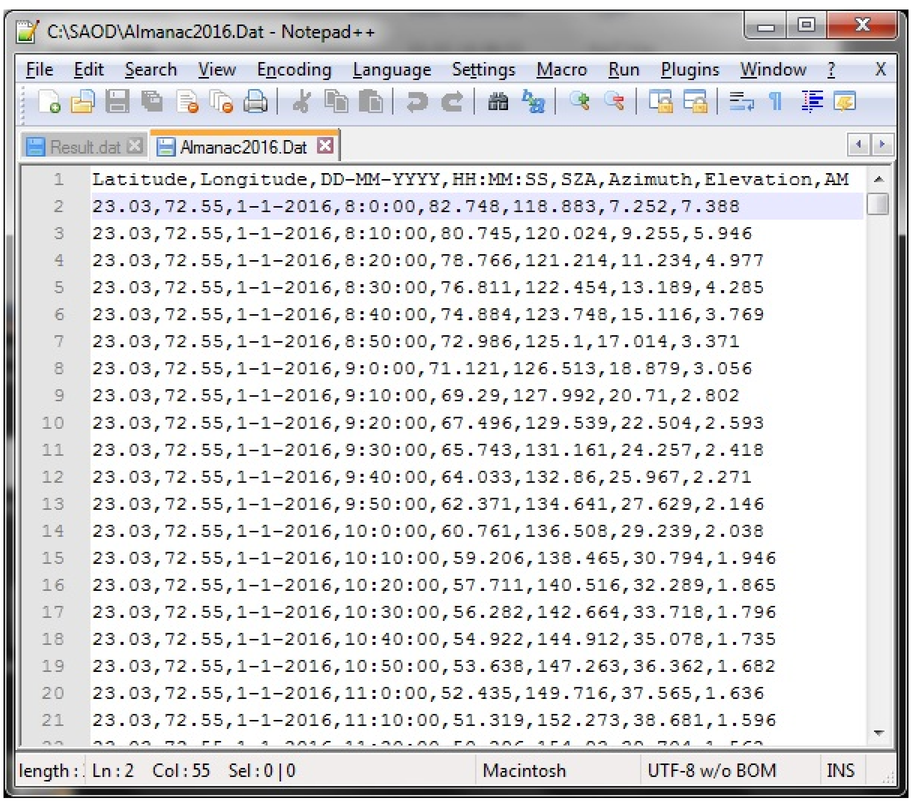

Figure 11. Almanac data computed over Ahmedabad for 2016 at every 10 minutes interval

the rapid application development (RAD) of graphical user interface (GUI) application software [13]. The setup and deployment packages was developed using Inno Setup Compiler 5.5.8 application package. Inno Setup is a free installer for Windows programs (http://www.innosetup.com/) and it supports every Microsoft Windows release (since 2000), creation of a single EXE to install the program, standard Windows wizard interface, customizable setup types (full, minimal and custom), complete uninstall capabilities, creation of shortcuts, creation of registry and .INI entries, secured and encrypted installs, and integrated pre-processor option for advanced compile-time customization. The GUI application software works in Microsoft Windows 7/8/8.1/10 operating system with .NET framework.

Figure 5 shows the flowchart of the ”Sun photometer computational software package” (SPCSP) version 4.6 GUI application software. SPCSP consists of six operational menu item; (i) Setup (ii) Compute (iii) Refresh (iv) About (v) Exit and (vi) Constants as shown in Figure 2. SPCSP can be configured through ‘Setup’ menu item and the various user editable parameters are (1) Station, (2) Instrument, (3) Latitude (N), (4) Longitude (E), (5) Altitude (m), (6) IST to UTC differences, (7) Data path, (8) No. of Channels, and (9) Channel Data. The present software has been designed to handle only maximum six channels optical data and can be configured accordingly. The setup parameters are saved at the user configured data path using the ”Save” command button (Figure 6). The ’Compute’ drop-down menu item has the following subitems (1) Solar Zenith Angle, (2) Rayleigh Optical Depth, (3) Ozone Optical Depth, and (4) Aerosol Optical Depth. Solar zenith angle menu subitem is used to compute the Julian day, solar zenith angle, azimuth, elevation and atmospheric airmass for the user configured latitude, longitude, date and time (Figure 7). In addition it is also used to compute and generate the almanac for the user configure year with specific time interval and for the preset time range (08:00 to 17:00 Hrs). Rayleigh optical depth (ROD) as a function of wavelength is computed using the Rayleigh optical depth menu subitem. ROD

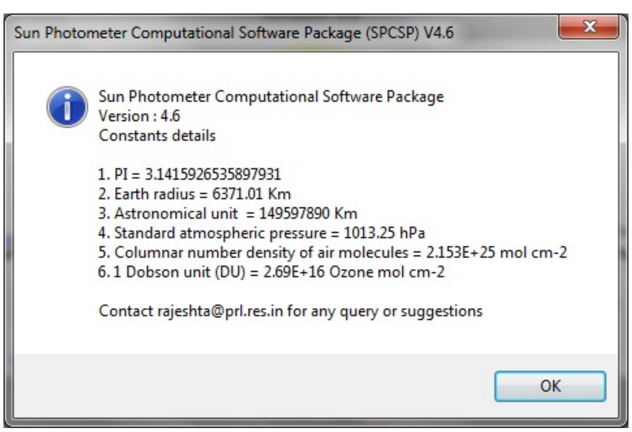

Figure 12. Computational constants used in SPCSP

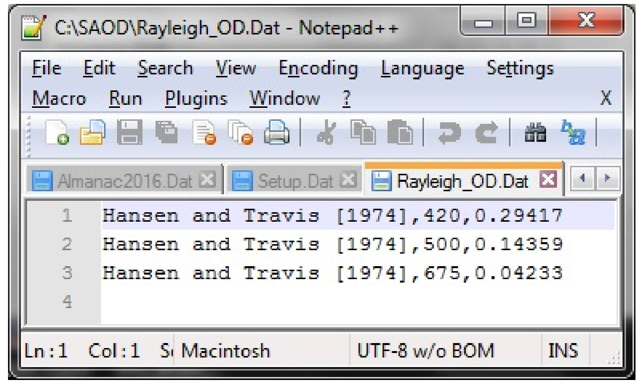

Figure 13. Rayleigh optical depth computed values for different wavelengths using the user selectable computational method and saved as Rayleigh_OD.Dat

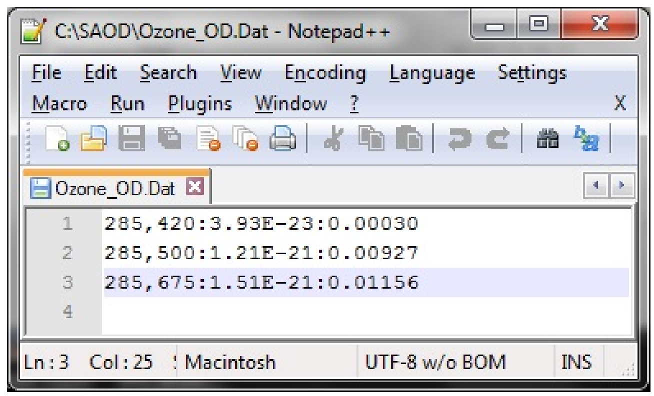

Figure 14. Molecular (Ozone) optical depth computed for different wavelengths and saved as Ozone_OD.Dat

computational method is selected using the combo box (Figure 8). Ozone optical depth is computed using the ’Ozone Optical Depth’ menu subitem for each wavelength with known absorption cross section and total column ozone (TCO) in Dobson unit (DU) (Figure 9). TCO values available in the downloaded OMI daily data files are manually fetched and input to the total column ozone (DU) field. Aerosol optical depth can be computed using ’Aerosol Optical Depth’ menu subitem, the GUI requires the user to provide the following input parameters; date and time of observation, and measured voltage for each wavelength (Figure 10). The other input required for the AOD computation are retrieved from the Setup.Dat configuration file. The ‘Refresh’ menu item reloads and initialize the software variables. ‘Exit’ menu item closes the various data files in use and quits the application software. ’Constants’ menu item shows the different scientific constant used in the software (Figure 12). When the SPCSP software is run for the first time, it will prompt to configure the application software and the parameters are saved in Setup.Dat file in the user configured data folder [15].

The steps involved in executing the program are as follows

1. Select the 'Setup' menu item and enter the setup parameters (without ROD and MOD in the first run) and save it.
2. Select the 'Compute' menu item and choose the 'Rayleigh Optical Depth' menu subitem. Select the required Rayleigh optical depth computational method and proceed to compute the ROD. Save the result for the record. Figure 13 shows the Rayleigh optical depth generated output file 'Rayleigh_OD.Dat'.
3. Select the 'Compute' menu item and choose the 'Ozone Optical Depth' menu subitem. Enter the absorption cross section of Ozone for the configured wavelengths and the daily mean total column Ozone (DU) for the measurement grid. Press 'Calculate' to compute the Ozone optical depth and save the result for record. Figure 14 shows the Ozone optical depth generated output file 'Ozone_OD.Dat'.
4. Select the 'Setup' menu item and enter the ROD and MOD values (obtained for the respective wavelengths using step 2 and 3) and save it. Figure 15 shows the setup file 'Setup.Dat'.
5. Select the 'Compute' menu item and choose the 'Aerosol Optical Depth' menu subitem. Enter the date (day, month and year), time (hour, minute and second) and the measured voltages for each wavelengths. Press 'Calculate' to compute the aerosol optical depth and save the result for record. Figure 16 illustrates the aerosol optical depth generated output file 'Data.Dat'.
6. Select the 'Compute' menu item and choose the 'Solar Zenith Angle' menu subitem. Enter location coordinates (latitude and longitude), date, and time in order to calculate the Julian day, solar zenith angle, azimuth, elevation and atmospheric airmass. Almanac for the year of interest can also be computed at time interval of 10 minutes for the preset diurnal time range. Figure 11 shows the almanac generated for the year 2016 over Ahmedabad at every 10 minutes interval.

5. Summary

The report discuss about the design, functions and processes of aerosol optical depth (AOD) computational software package (SPCSP) for the hand-held Sun photometer. The graphical user interface application software package (SPCSP) has been developed in-house using Microsoft Visual Basic 2010.NET rapid application development object oriented programming language. It is used to compute and study the Rayleigh optical depth using Hansen and Travis (1974), Frohlich and Shaw (1980), Nicolet (1984), and Bodhaine et al (1999) methods. The user can compute the Ozone optical depth with the known absorption cross section of Ozone and the average total column Ozone (DU) over the study location. The setup parameters can be configured and saved with channel wavelengths, given V_0, and computed Rayleigh optical depth (ROD) and Ozone optical depth (MOD). Once the setup parameters are fully configured the aerosol optical depth can be computed for the measured voltages and estimated dark current for each channel. The present software package has been designed to handle only maximum six channels optical data. The computed Rayleigh optical depth, Ozone optical depth, and AOD data are saved into files in ASCII format. The SPCSP software package is made compatible to Microsoft Windows 7/8/8.1/10 operating system with .NET framework. The GUI application software package is made available in the installer setup and deployment format.

Acknowledgements

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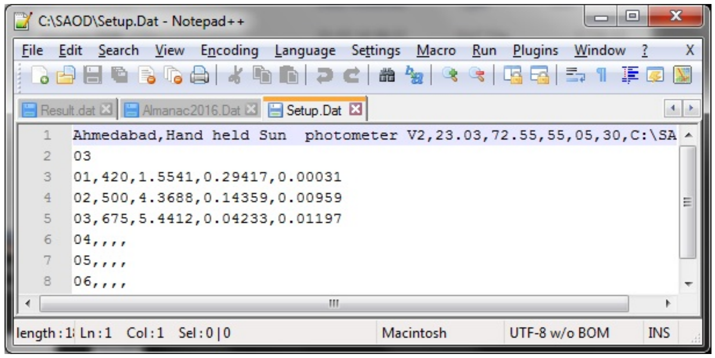

Figure 15. Setup file (Setup.Dat) generated for SPCSP

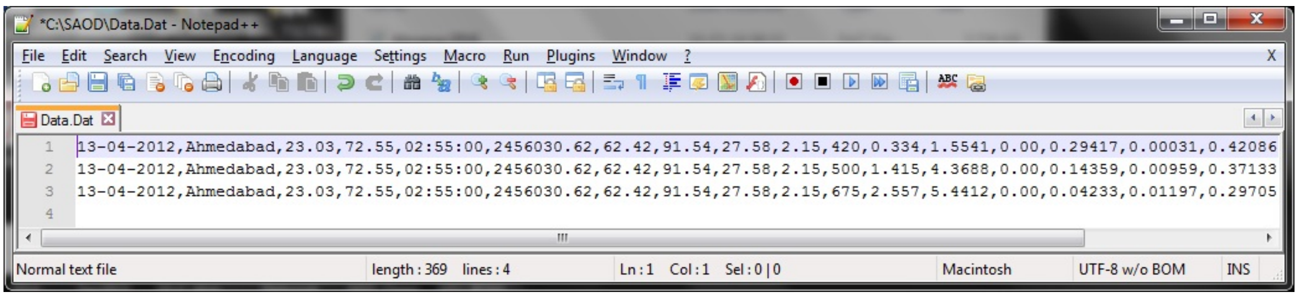

Figure 16. Computed AOD data along with other values (station, latitude, longitude, date, time, Julian day, solar zenith angle, wavelength, ROD and MOD) and saved as Data.Dat

6. Appendix 1: Computation of solar zenith angle

The motions of Earth is usually computed in ecliptic coordinate system, based on the plane of the ecliptic and the position of an object is defined by the ecliptic latitude, the ecliptic longitude, and the distance. The ecliptic coordinates are transformed to celestial or equatorial coordinates (right ascension, declination). Finally, the equatorial coordinate system are then transformed to observer's or horizon coordinate system to yield the altitude, azimuth, hour angle (HA) and solar zenith angle (θ). Equation 22 - 45 illustrates the various steps involved in the computation of solar zenith angle (θ) and the input variables are date (day, month and year), hours in decimal (DHours), longitude (ψ), and latitude (ϕ). Various intermediate generated variables are Julian date (JD), elapsed Julian days (EJD), ecliptic obliquity (EO), ecliptic longitude (EL), mean anomaly (MA), mean longitude (ML), Greenwich mean Sidereal time (GMST), local mean Sidereal time (LMST), right ascension (RA) and declination (δ).

$$DHours = Hour + \frac{Minute}{60} + \frac{Second}{3600} \tag{22}$$

$$v1 = \frac{Month - 14}{12} \tag{23}$$

$$v2 = 1461\ \frac{Year + 4800 + v1}{4} \tag{24}$$

$$v3 = 367\ \frac{Month - 2 - 12 * v1}{12} \tag{25}$$

$$v4 = 3\ \frac{(Year + 4900 + v1)/100}{4} \tag{26}$$

$$v5 = Day - 32075 \tag{27}$$

$$JD = v2 + v3 - v4 + v5 - 0.5 + \frac{DHours}{24} \tag{28}$$

$$EJD = JD - 2451545 \tag{29}$$

$$Omega = 2.1429 - 0.0010394594\ EJD \tag{30}$$

$$ML = 4.895063 + 0.017202791698\ EJD \tag{31}$$

$$MA = 6.24006 + 0.0172019699\ EJD \tag{32}$$

$$v6 = ML + 0.03341607\ Sin(MA) \tag{33}$$

$$v7 = 0.00034894\ Sin(2\,MA) \tag{34}$$

$$v8 = 0.0001134 + 0.0000203\ Sin(Omega) \tag{35}$$

$$EL = v6 + v7 - v8 \tag{36}$$

$$EO = 0.4090928 - 0.000000006214\ EJD + 0.0000396\ Cos(Omega) \tag{37}$$

$$dY = Cos(EO)\ Sin(EL) \tag{38}$$

$$dX = Cos(EL) \tag{39}$$

$$RA = Atan(dY, dX) \tag{40}$$

$$\delta = Asin(Sin(EO) * Sin(EL)) \tag{41}$$

$$GMST = 6.6974243242 + 0.0657098283\ EJD + DHours \tag{42}$$

$$LMST = 15 * GMST + \psi \tag{43}$$

$$HA = LMST - RA \tag{44}$$

$$\theta = Acos(Cos(\phi)\ Cos(HA)\ Cos(\delta) + Sin(\delta)\ Sin(\phi)) \tag{45}$$

7. Appendix 2: Absorption cross-section of Ozone

Absorption cross-section for Ozone [σ_{O_3}]

$\lambda\,[nm]$	$\sigma_{O_3}\,[cm^2]$	$\lambda\,[nm]$	$\sigma_{O_3}\,[cm^2]$	$\lambda\,[nm]$	$\sigma_{O_3}\,[cm^2]$	$\lambda\,[nm]$	$\sigma_{O_3}\,[cm^2]$
350.5	3.06E-22	400.5	1.15E-23	450.5	1.85E-22	500.5	1.21E-21
351.5	3.06E-22	401.5	1.15E-23	451.5	1.85E-22	501.5	1.21E-21
352.5	1.36E-22	402.5	1.58E-23	452.5	2.18E-22	502.5	1.60E-21
353.5	1.36E-22	403.5	1.58E-23	453.5	2.18E-22	503.5	1.60E-21
354.5	1.36E-22	404.5	1.58E-23	454.5	2.18E-22	504.5	1.60E-21
355.5	1.36E-22	405.5	1.58E-23	455.5	2.18E-22	505.5	1.60E-21
356.5	1.36E-22	406.5	1.58E-23	456.5	2.18E-22	506.5	1.60E-21
357.5	6.94E-23	407.5	2.58E-23	457.5	3.66E-22	507.5	1.58E-21
358.5	6.94E-23	408.5	2.58E-23	458.5	3.66E-22	508.5	1.58E-21
359.5	6.94E-23	409.5	2.58E-23	459.5	3.66E-22	509.5	1.58E-21
360.5	6.94E-23	410.5	2.58E-23	460.5	3.66E-22	510.5	1.58E-21
361.5	6.94E-23	411.5	2.58E-23	461.5	3.66E-22	511.5	1.58E-21
362.5	3.05E-23	412.5	2.95E-23	462.5	3.67E-22	512.5	1.66E-21
363.5	3.05E-23	413.5	2.95E-23	463.5	3.67E-22	513.5	1.66E-21
364.5	3.05E-23	414.5	2.95E-23	464.5	3.67E-22	514.5	1.66E-21
365.5	3.05E-23	415.5	2.95E-23	465.5	3.67E-22	515.5	1.66E-21
366.5	3.05E-23	416.5	2.95E-23	466.5	3.67E-22	516.5	1.66E-21
367.5	1.30E-23	417.5	3.93E-23	467.5	4.10E-22	517.5	1.83E-21
368.5	1.30E-23	418.5	3.93E-23	468.5	4.10E-22	518.5	1.83E-21
369.5	1.30E-23	419.5	3.93E-23	469.5	4.10E-22	519.5	1.83E-21
370.5	1.30E-23	420.5	3.93E-23	470.5	4.10E-22	520.5	1.83E-21
371.5	1.30E-23	421.5	3.93E-23	471.5	4.10E-22	521.5	1.83E-21
372.5	8.50E-24	422.5	6.56E-23	472.5	4.81E-22	522.5	2.19E-21
373.5	8.50E-24	423.5	6.56E-23	473.5	4.81E-22	523.5	2.19E-21
374.5	8.50E-24	424.5	6.56E-23	474.5	4.81E-22	524.5	2.19E-21
375.5	8.50E-24	425.5	6.56E-23	475.5	4.81E-22	525.5	2.19E-21
376.5	8.50E-24	426.5	6.56E-23	476.5	4.81E-22	526.5	2.19E-21
377.5	5.72E-24	427.5	6.97E-23	477.5	7.54E-22	527.5	2.67E-21
378.5	5.72E-24	428.5	6.97E-23	478.5	7.54E-22	528.5	2.67E-21
379.5	5.72E-24	429.5	6.97E-23	479.5	7.54E-22	529.5	2.67E-21
380.5	5.72E-24	430.5	6.97E-23	480.5	7.54E-22	530.5	2.67E-21
381.5	5.72E-24	431.5	6.97E-23	481.5	7.54E-22	531.5	2.67E-21
382.5	5.42E-24	432.5	8.82E-23	482.5	8.13E-22	532.5	2.87E-21
383.5	5.42E-24	433.5	8.82E-23	483.5	8.13E-22	533.5	2.87E-21
384.5	5.42E-24	434.5	8.82E-23	484.5	8.13E-22	534.5	2.87E-21
385.5	5.42E-24	435.5	8.82E-23	485.5	8.13E-22	535.5	2.87E-21
386.5	5.42E-24	436.5	8.82E-23	486.5	8.13E-22	536.5	2.87E-21
387.5	6.68E-24	437.5	1.37E-22	487.5	8.16E-22	537.5	2.95E-21
388.5	6.68E-24	438.5	1.37E-22	488.5	8.16E-22	538.5	2.95E-21
389.5	6.68E-24	439.5	1.37E-22	489.5	8.16E-22	539.5	2.95E-21
390.5	6.68E-24	440.5	1.37E-22	490.5	8.16E-22	540.5	2.95E-21
391.5	6.68E-24	441.5	1.37E-22	491.5	8.16E-22	541.5	2.95E-21
392.5	9.56E-24	442.5	1.65E-22	492.5	9.08E-22	542.5	3.19E-21
393.5	9.56E-24	443.5	1.65E-22	493.5	9.08E-22	543.5	3.19E-21
394.5	9.56E-24	444.5	1.65E-22	494.5	9.08E-22	544.5	3.19E-21
395.5	9.56E-24	445.5	1.65E-22	495.5	9.08E-22	545.5	3.19E-21
396.5	9.56E-24	446.5	1.65E-22	496.5	9.08E-22	546.5	3.19E-21
397.5	1.15E-23	447.5	1.85E-22	497.5	1.21E-21	547.5	3.37E-21
398.5	1.15E-23	448.5	1.85E-22	498.5	1.21E-21	548.5	3.37E-21
399.5	1.15E-23	449.5	1.85E-22	499.5	1.21E-21	549.5	3.37E-21

$\lambda[nm]$	$\sigma_{O_3}[cm^2]$	$\lambda[nm]$	$\sigma_{O_3}[cm^2]$	$\lambda[nm]$	$\sigma_{O_3}[cm^2]$	$\lambda[nm]$	$\sigma_{O_3}[cm^2]$
550.5	3.37E-21	600.5	5.13E-21	671.5	1.70E-21	771.5	2.60E-22
551.5	3.37E-21	601.5	5.13E-21	673.5	1.51E-21	773.5	2.94E-22
552.5	3.58E-21	602.5	5.14E-21	675.5	1.51E-21	775.5	2.94E-22
553.5	3.58E-21	603.5	5.14E-21	677.5	1.37E-21	777.5	3.18E-22
554.5	3.58E-21	604.5	5.14E-21	679.5	1.37E-21	779.5	3.18E-22
555.5	3.58E-21	605.5	5.14E-21	681.5	1.37E-21	781.5	3.18E-22
556.5	3.58E-21	606.5	5.14E-21	683.5	1.26E-21	783.5	2.62E-22
557.5	3.98E-21	607.5	4.78E-21	685.5	1.26E-21	785.5	2.62E-22
558.5	3.98E-21	608.5	4.78E-21	687.5	1.13E-21	787.5	2.08E-22
559.5	3.98E-21	609.5	4.78E-21	689.5	1.13E-21	789.5	2.08E-22
560.5	3.98E-21	610.5	4.78E-21	691.5	1.13E-21	791.5	2.08E-22
561.5	3.98E-21	611.5	4.78E-21	693.5	9.89E-22	793.5	1.73E-22
562.5	4.39E-21	612.5	4.38E-21	695.5	9.89E-22	795.5	1.73E-22
563.5	4.39E-21	613.5	4.38E-21	697.5	8.68E-22	797.5	1.57E-22
564.5	4.39E-21	614.5	4.38E-21	699.5	8.68E-22	799.5	1.57E-22
565.5	4.39E-21	615.5	4.38E-21	701.5	8.68E-22	801.5	1.57E-22
566.5	4.39E-21	616.5	4.38E-21	703.5	7.84E-22	803.5	1.56E-22
567.5	4.67E-21	617.5	4.06E-21	705.5	7.84E-22	805.5	1.56E-22
568.5	4.67E-21	618.5	4.06E-21	707.5	7.31E-22	807.5	1.86E-22
569.5	4.67E-21	619.5	4.06E-21	709.5	7.31E-22	809.5	1.86E-22
570.5	4.67E-21	620.5	4.06E-21	711.5	7.31E-22	811.5	1.86E-22
571.5	4.67E-21	621.5	4.06E-21	713.5	6.96E-22	813.5	2.21E-22
572.5	4.81E-21	622.5	3.82E-21	715.5	6.96E-22	815.5	2.21E-22
573.5	4.81E-21	623.5	3.82E-21	717.5	6.22E-22	817.5	2.06E-22
574.5	4.81E-21	624.5	3.82E-21	719.5	6.22E-22	819.5	2.06E-22
575.5	4.81E-21	625.5	3.82E-21	721.5	6.22E-22	821.5	2.06E-22
576.5	4.81E-21	626.5	3.82E-21	723.5	5.43E-22	823.5	1.45E-22
577.5	4.64E-21	627.5	3.56E-21	725.5	5.43E-22		
578.5	4.64E-21	628.5	3.56E-21	727.5	4.78E-22		
579.5	4.64E-21	629.5	3.56E-21	729.5	4.78E-22		
580.5	4.64E-21	631.5	3.56E-21	731.5	4.78E-22		
581.5	4.64E-21	633.5	3.27E-21	733.5	4.42E-22		
582.5	4.46E-21	635.5	3.27E-21	735.5	4.42E-22		
583.5	4.46E-21	637.5	2.97E-21	737.5	4.32E-22		
584.5	4.46E-21	639.5	2.97E-21	739.5	4.32E-22		
585.5	4.46E-21	641.5	2.97E-21	741.5	4.32E-22		
586.5	4.46E-21	643.5	2.71E-21	743.5	4.47E-22		
587.5	4.47E-21	645.5	2.71E-21	745.5	4.47E-22		
588.5	4.47E-21	647.5	2.51E-21	747.5	4.25E-22		
589.5	4.47E-21	649.5	2.51E-21	749.5	4.25E-22		
590.5	4.47E-21	651.5	2.51E-21	751.5	4.25E-22		
591.5	4.47E-21	653.5	2.31E-21	753.5	3.38E-22		
592.5	4.76E-21	655.5	2.31E-21	755.5	3.38E-22		
593.5	4.76E-21	657.5	2.10E-21	757.5	2.86E-22		
594.5	4.76E-21	659.5	2.10E-21	759.5	2.86E-22		
595.5	4.76E-21	661.5	2.10E-21	761.5	2.86E-22		
596.5	4.76E-21	663.5	1.90E-21	763.5	2.62E-22		
597.5	5.13E-21	665.5	1.90E-21	765.5	2.62E-22		
598.5	5.13E-21	667.5	1.70E-21	767.5	2.60E-22		
599.5	5.13E-21	669.5	1.70E-21	769.5	2.60E-22		