ARM TR-056

Cimel Sunphotometer (CSPHOT) Handbook

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1. General Overview

The Cimel sunphotometer (CSPHOT) is a multi-channel, automatic sun-and-sky scanning radiometer that measures the direct solar irradiance and sky radiance at the Earth's surface. Measurements are taken at pre-determined discrete wavelengths in the visible and near-IR parts of the spectrum to determine atmospheric transmission and scattering properties. This instrument is weather-proof and requires little maintenance during periods of adverse weather conditions. It takes measurements only during daylight hours (sun above horizon).

2. Contacts

2.1 Mentor

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2.2 Instrument Developer

This section is not applicable to this instrument.

3. Deployment Locations and History

A Cimel sunphotometer was successfully installed for long-term operations at the SGP site in March 1998. Another CSPHOT has been deployed at Nauru.

As of 2004-10-01, ARM owns and operates two CSPHOTs in the field, one at SGP CF, one at TWP C2 (Nauru), and two other spare units. AERONET also obtains data from CSPHOTs owned by other agencies, one at TWP C3 (Darwin) and one at NSA C1 (Barrow).

4. Near-Real-Time Data Plots

This section is not applicable to this instrument.

5. Data Description and Examples

Current and recent data quicklooks – Go to Real Time Data (Level 1).

AOT and PW as a function of time are depicted in the following Figures 1 and 2 as a function of time for one day. Also shown in Figure 3, are results of almucantar scan, size distribution derived from almucantar data using Nakajima's method (Nakajima et al. 1983) and phase function derived from the size distribution using the same method.

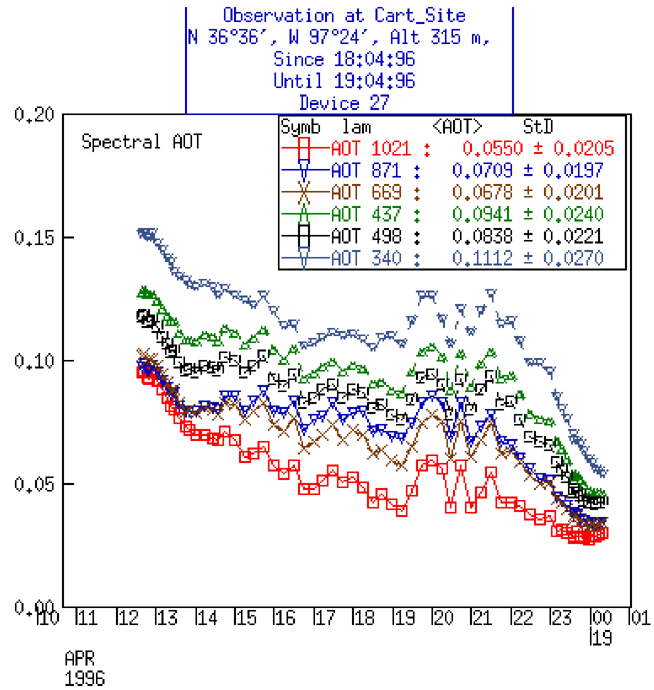

Figure 1.

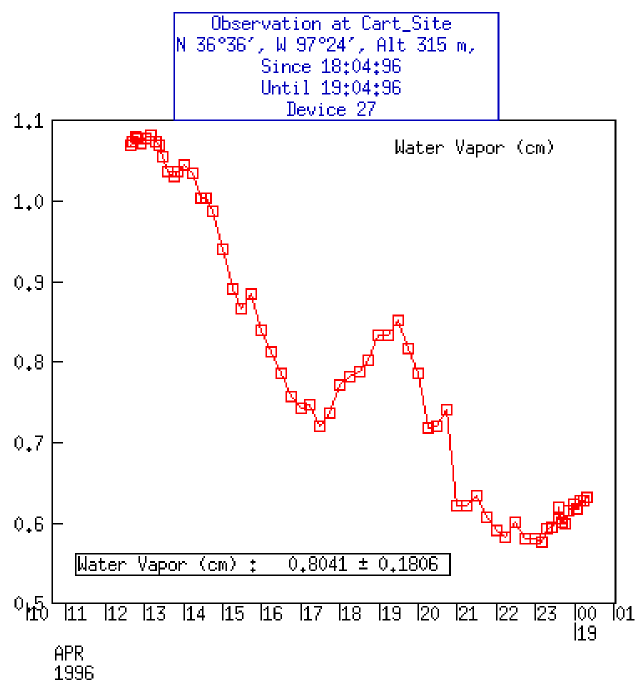

Figure 2.

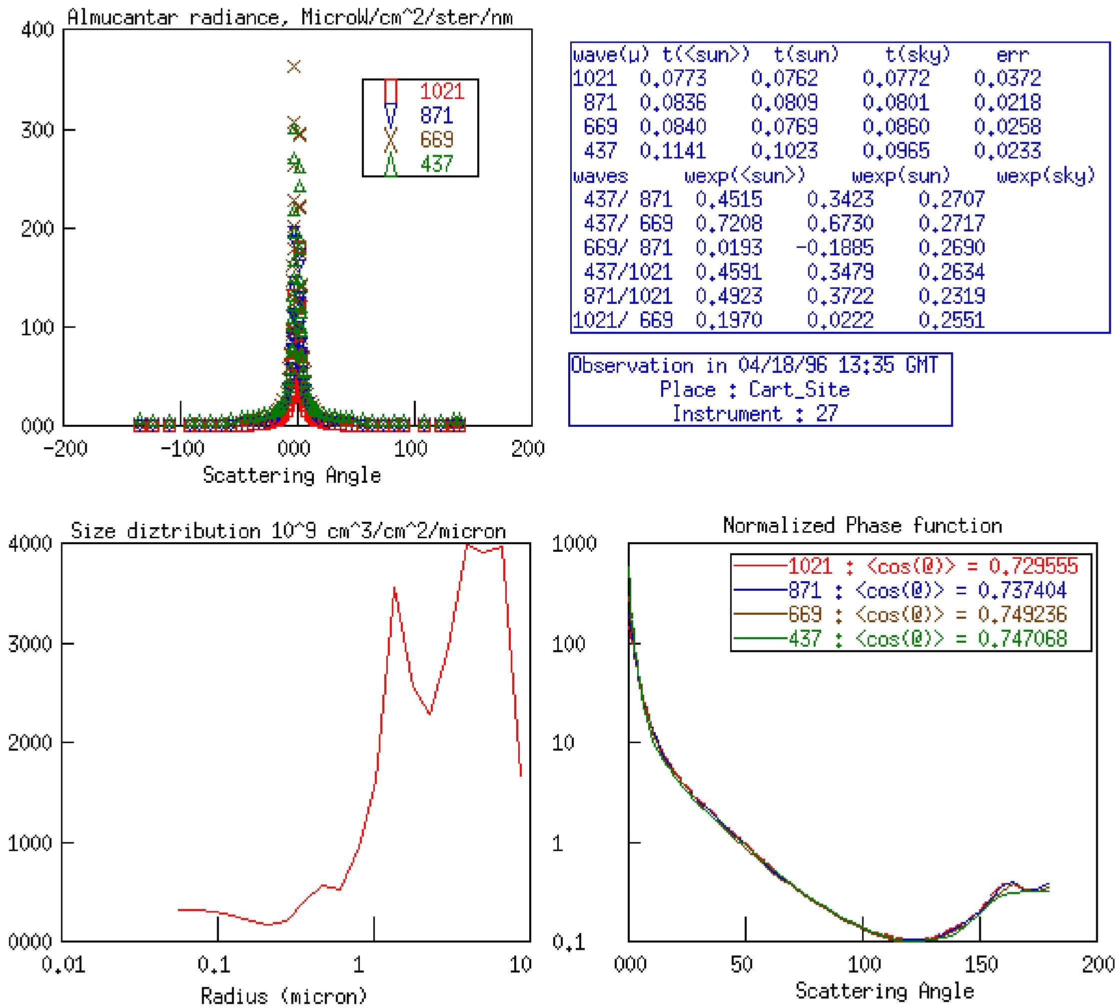

Figure 3.

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

Atmospheric transmission is measured from the direct-normal solar irradiance measurement (sunphotometric operation). Vertical aerosol optical thickness is derived to an accuracy of ± 0.02 - 0.04 at an airmass of 2. Water vapor column abundance is measured to an accuracy of ± 10%. Aerosol size distribution in the 0.1 to 3 micron size range is derived from the sky radiance measurements (radiometric operation) using radiative transfer algorithms. Phase function is obtained from the size distribution. The accuracy of the latter derived products is unknown.

5.1.1.1 Definition of Uncertainty

The primary quantities measured by the CSPHOT are as follows: the aerosol optical thickness, water vapor column abundance, aerosol size distribution, and the aerosol phase function. Calibration introduces a major uncertainty in the determination of the above quantities, especially the optical thickness and the water column abundance. It is expected that the AOT can be determined to an accuracy of ± 0.01 and water vapor column abundance to an accuracy of ± 10%. The accuracy in the determination of the size distribution and phase function is not yet assessed. In fact, inversion radiative transfer algorithms, such as those used here to invert the aureole brightness (Nakajima et al. 1983), provide non-unique size distribution for observations in the visible and near-IR. It is debatable whether size distribution beyond about 3 micron is reliable at all. It is recommended that the size distribution data be used for qualitative assessment of the nature of the aerosol size distribution.

The data will be supplied to the ARM database as external data and will have passed all quality checks. The issue of primary concern is the presence of clouds as the clouds may distort the data. Clouds will be removed by inspection of triplet measurement and by eliminating all data showing an Angstrom exponent of less than 0.5.

5.1.2 Secondary/Underlying Variables

This section is not applicable to this instrument.

5.1.3 Diagnostic Variables

This section is not applicable to this instrument.

5.1.4 Data Quality Flags

This section is not applicable to this instrument.

5.1.5 Dimension Variables

This section is not applicable to this instrument.

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

The data are processed and quality controlled by AERONET at NASA. ARM reingests these data as external data, see external data stream description.

5.4 Frequently Asked Questions

This section is not applicable to this instrument.

6. Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results:

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

- **QC frequency**: Daily and weekly checks
- **QC delay**: Not specified
- **QC type**: Comparisons with normal standards; reviews of the symmetry of sky radiance scans (to check for automatic gain performances); comparisons with MFRSR data; water vapor column abundance comparisons with estimates derived from BBSS and MWR observations
- **Inputs**: Transmitted signal from GOES satellite at NASA Wallops Island Facility
- **Outputs**: Data flags in headers
- **Reference**: None.

After the CSPHOT is installed at the SGP central facility in early 1998, data will be collected via GOES satellite at the National Aeronautics and Space Administration (NASA) Wallops Island Facility. Information on the transmitted signal will be inspected for signal strength, transmission time, and time interval between transmissions.

Daily and weekly checks will be routinely made on the data. The Cimel clock time, Cimel battery power, GOES Transmission Module (GTM) clock time, and its battery power will be checked. Daily and weekly checks of measured Aerosol Optical Thickness (AOT) in different channels will be made to isolate inadequately performing channels. Symmetry of sky radiance scans (almucantar and principle plane scans) will be inspected to check automatic gain performance. After such data quality control procedures are applied and data are flagged appropriately, the data will be made available to ARM data users as external data

Calibrations are performed once a year either at the mountain-top sites or by comparisons at NASA Goddard Space Flight Center (GSFC) with other sensors that have been at such sites. Once a month, Langley analyses will be carried out to infer sensitivities, which will be compared to those derived from the annual calibrations. In addition, the AOT data will compared with those derived from MFRSRs, and water vapor column abundance using a modified Langley approach will be compared with estimates derived from BBSS and MWR observations.

6.3 Data Assessments by Site Scientist/Data Quality Office

Quality control is provided by AERONET during processing and retrieval of geophysical quantities.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysis and processing of existing data products into “value-added” products or VAPs. Despite extensive instrumentation deployed at the ARM CART sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but instead to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces “best estimate” VAPs. A special class of VAP called a Quality Measurement Experiment (QME) does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information, see the VAPs and QMEs web page.

For the CSPHOT, size distribution and phase function can be considered as value-added products. The AOT comparison with MFRSR derived values and the PW comparison with radiosonde and micro-wave radiometer values are QMEs.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The CSPHOT consists of (1) the instrument itself (made up of the sensor head and scanning motors and robot arm); (2) a control box (provides software for controlling predetermined scanning and sampling strategies, for acquiring data, and for formatting remote satellite-based transmissions and batteries); and (3) a radio antenna (for transmitting data to a GOES satellite). The instrument is made by Cimel Electronique of France; the GOES transmitter module (GTM) and antenna are made by Vitel Corporation (USA). Figure 4 presents a schematic of a CSPHOT in a mounted configuration.

7.1.2 System Configuration and Measurement Methods

The following paragraphs describe the components that make up the system (see Figure 5).

Instrument (Figure 5)

The instrument consists of the main stem containing the azimuth motor, on the top of the motor is an attached a robot arm consisting of the zenith motor on one side and the sensor head on the other side. The collimators are attached to the sensor head. Inside the sensor head are two silicon detectors, one for each of the collimators. A filter wheel is placed in between the collimator windows and the detectors, inside the sensor head. The wheel consists of eight narrowband interference filters (at 340, 378, 440, 499, 613, 870, 940 and 1020 nm) mounted along the circumference. The two collimators have the same field of view (1.2 degree) but differ in the size of apertures. They are physically part of a single unit that is attached to the sensor head by a long screw tightened down to prevent light and water leakage. The larger aperture collimator--10 times as large as the sun-viewing collimator--provides the necessary dynamic range to observe the sky. Three cables (a thick cable from the sensor head to the control box, and two battery power cables--one each to the motors) are attached to the instrument. The main stem is connected to a base plate consisting of mounting holes to ensure the instrument is mounted on a level surface.

Schematic of CSPOT Systems and Mounting Configuration

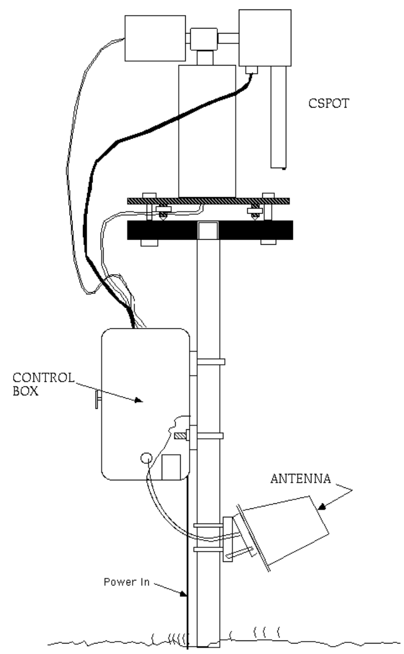

Figure 4.

CSPOT Instrument Parts and Operation

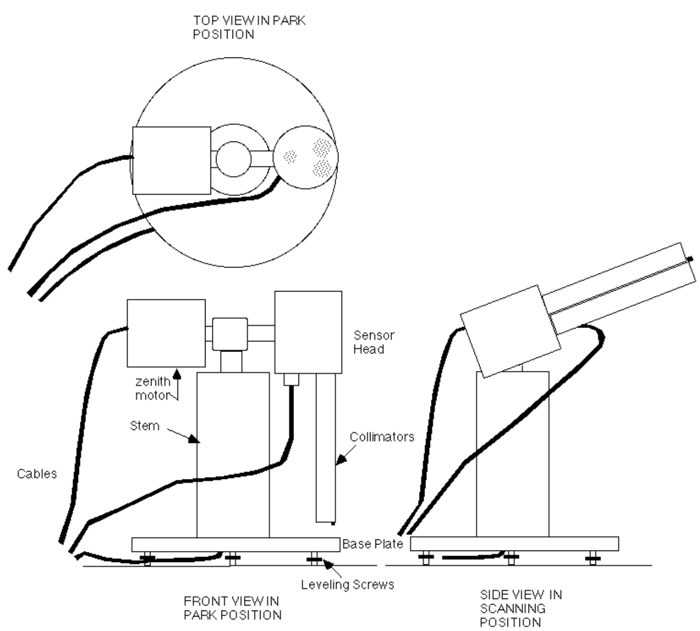

Figure 5.

Control boxes

The Cimel control box consists of a control module--a rectangular-shaped white box--that actually controls the scan and measurement sequence of CSPHOT. It has an internal battery that services only the software portion of the instrument. The box also stores data that can be queried and transferred upon demand by the GOES Transmission Module (GTM). The GTM is also housed in the control box and physically consists of two parts: the GTM control box that schedules and formats data for transmission, and an amplifier box that boosts the signal for transmittal through the antenna. The control box also includes a battery pack that supplies power to the CSPHOT control box, the GTM. A separate battery charger provides the necessary power from the input mains.

Antenna

The antenna is connected to the GTM amplifier through a 6-foot, heavy-duty coaxial cable. The antenna points South - South-East at the CART site to enable transmission to the GOES East satellite. The antenna transmits data every hour at a predetermined time and takes up to a maximum of 2 minutes. The frequency for transmission is 401.76 MHz. The password code and duration and time of transmission are all set in the GTM control box.

Location (Siting)

The instrument is located at a height of about 5 feet from the surface to minimize accidental obstruction of the field of view of the collimators. The location should allow an unobstructed view of the sky above 5 degrees of elevation, especially in the general region of sunset and sunrise at the CART site.

Weather-Related Details

All the cables interconnecting the above components pass through rainproof silicone seals in their respective boxes. A wet sensor, connected to the instrument control box, effectively shuts down the scanning by the sensor head during precipitation. The fail-safe pointing for the sensor head is the “down” position with the collimators pointing down toward the base.

Measurement Method

Cimel operates automatically without operator assistance as with other ARM instruments. It measures direct solar irradiance by first pointing the collimator toward the approximate position of the sun (provided it is aligned properly) based on an in-built program that takes into account the time of the year and the coordinates of the location that are input to the Cimel control box prior to operation. A 4-quadrant detector then positions the sun at the center of the fields of view of the collimators by using a feedback control loop. The filter wheel rotates in front of the detector to obtain a measurement sequence. A sequence takes about 10 seconds. In order to discriminate against the presence of thin cirrus clouds, which may be non-uniform, three measurement sequences are performed (called as a triplet), lasting about 35 seconds. During a data analysis procedure, the measured voltages are compared to eliminate non-uniform scenes. Almucantar sky radiance is obtained by scanning the sky at the solar zenith angle but different azimuth angles to obtain the angular variation of skylight in 4 filters. Solar principal plane sky measurement is obtained by scanning the sky in a plane containing the sun and the instrument and normal to the surface. Data are taken more frequently near the sun since the intensity varies rapidly in the solar aureole. The sky brightness data is inverted by radiative transfer routines to derive aerosol size distribution and phase function.

Data Acquisition

Direct solar irradiance data are obtained in all the filters every 0.5 airmasses above an airmass of 2, and every 15 minutes otherwise. Solar almucantar data (sky radiance at constant solar zenith angle) are obtained twice daily when weather permits at a solar zenith angle of approximately 60 degrees in 4 channels - 440, 499, 613, 870 nm. Solar principal plane sky radiance is obtained 4 times daily in the same channels as for the almucantar. All the data are stored in memory in the Cimel control box. At predetermined times, a minute before the hourly GOES transmission, the GTM acquires and formats the data for the transmission. The data are transmitted to a computer at NASA's Wallops Island Facility from where the data are downloaded to computers at Goddard Space Flight Center. Since the ARM Cimels are also part of Aeronet network (Holben et al. 1997), the data are automatically analyzed for the required parameters.

7.1.3 Specifications

AOT is measured at 440, 499, 670, 870, and 1019 nm, typically. Additional wavelengths are at 339 and 380 nm where some ozone absorption is present. The primary purpose of 940 nm filter band is to measure column water vapor. All filters have a narrow bandwidth of about 10 nm. The following table summarizes the instrument characteristics and observational specifications.

Table 1. Instrument Characteristics and Observational Specifications

Detector:	Silicon
Number of Filters:	5 to 8
Number of collimators:	2
Field of View/ Aperture:	1.2. One has 10 times the aperture of the other.
Solar Scanning:	4 quadrant detector.
Sky scanning:	Azimuth and Zenith motors.
Frequency of Sun acquisition:	0.5 airmass intervals for airmass > 2. Otherwise, 15 minutes apart.
Frequency of Almucantar:	At airmass of 4 and 2. 4 times daily.

7.2 Theory of Operation

Direct Normal Solar Irradiance E (W/m^2) at the surface at a given wavelength is given by Bouguer's law,

E=(E_0/R^2)exp(-m*tau)

where E_0 is the extra-terrestrial solar irradiance at a distance of 1 Astronomical Unit (AU), R is the sun-earth distance in AU at the time of measurement, m is the airmass and tau is the total vertical optical thickness. If the instrument is voltage V for irradiance E, the above equation can be written as,

$$V=(V_0/R^2) \exp(-m*tau) \quad ....(1)$$

V_0 on the right hand side of this equation is the calibration coefficient obtained by measuring voltage V as a function of airmass m and extrapolating the resulting curve to zero airmass. The total optical thickness tau is made up of molecular (Rayleigh) attenuation, trace gas attenuation (such as ozone) and of course aerosol attenuation. By appropriately estimating the molecular contributions, aerosol optical thickness can be estimated. The accuracy in the estimation depends on the uncertainty in V and uncertainty in V_0. The former is a function of the precision of the silicon detector which is very high and therefore can be neglected. Accuracy in the calibration coefficient determination will be discussed in the calibration section.

For the 940 nm channel Bouguer's law is not valid since the exponential attenuation law is valid strictly for monochromatic radiation. For a band attenuation, preferential attenuation at the line centers results quickly in saturation and further passage through the atmosphere follows exponential attenuation law only in the pressure broadened line wings where the attenuation is weaker. Transmission can be modeled as a two parameter expression (Halthore et al. 1997) thus:

$$T=\exp(-a*w^b)$$

where T is the transmission in the band, a and b are constants that are determined by modeling with a radiative transfer equation and convolving the result with the shape of the 940 nm band, for a given atmosphere. Halthore et al. (1997) showed that by choosing a narrow 940 nm band width, sensitivity to atmosphere can be removed resulting in a equation of type,

$$V=(V_0/R^2)* \exp(-m*tau)* \exp(-a*w^b) \quad ....(2)$$

for any atmosphere. The optical thickness tau here comprises of Rayleigh and aerosol components which are estimated independently (by interpolation in the case of aerosol). w the water column abundance, = m * PW, where PW, the perceptible water, is obtained once the calibration constant is known. Calibration for the 940 nm channel is accomplished in a manner similar to the previous case and is described below.

7.3 Calibration

7.3.1 Theory

Calibration for the non-water absorbing channels is performed by the Langley method. Taking logarithms on both sides of the equation (1) and separating the total optical thickness to its components, we get,

$$\ln V + m\ tau\_R + m*\ tau\_oz = \ln (V\_0/ R^2) - m * tau\_aer$$

Measurements of voltage for each channel are taken frequently during periods of maximum airmass change, that is sunrise and sunset, above zenith angle of 60 degrees. A practical upper limit for airmass is usually 6 or 7, determined by the inability to account for refractive index effects in the atmosphere. With the Rayleigh, and any gaseous absorption accounted for in each channel, the left hand side of the above equation is plotted against airmass m to yield a straight line if the aerosol optical thickness tau_aer remains constant during the time of measurement. The intercept is the required calibration coefficient Vo and the slope gives the aerosol optical thickness during calibration. Langley plots are best performed when aerosol is both constant and low during the time of measurement, conditions that are best achieved at mountain sites during morning when the convective activity has not yet built up.

For the 940 nm channel, calibration is performed by the modified-Langley method. This is best illustrated by taking logarithms on both side of equation (2) to obtain,

$$\ln V + m^* \tau = \ln (V_0 / R^2) - a * PW^b * m^b$$

where the column abundance along the path, w, is written in terms of the product of the perceptible water which is the water vapor vertical column abundance and airmass m. Thus, a plot of the left hand side versus m^b will yield a straight line if in addition to the aerosol optical thickness (contained in the ordinate), PW also remains constant. AOT is estimated for the 940 nm channel by interpolation between 870 and 1020 nm channels. Here a and b are constants that are determined (Halthore et al. 1997) by running a radiative transfer model such as MODTRAN-3 and convolving its output with the measured filter function of the 940-nm band. Narrow band widths yield values of a and b that are independent of the type of atmosphere present.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

Any change in the calibration coefficients will be documented and the calibration event and the method will be listed in one file which will be part of the database. Uncertainties in the estimates will be given with their effect on the derived parameters of AOT and PW, and the size distribution.

7.4 Operation and Maintenance

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

This section is not applicable to this instrument.

7.4.3 Software Documentation

This section is not applicable to this instrument.

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

See the ARM Glossary.

7.6 Acronyms

See the ARM Acronyms and Abbreviations.

7.7 Citable References

Halthore, R.N., T.F. Eck, B.N. Holben, and B.L. Markham. 1997. Sunphotometric Measurements of Atmospheric Water Vapor Column Abundance in the 940-nm Band. *J. Geophys. Res.*, 102, 4343-4352.

Holben, B.N., T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer, E. Vermote, J. Reagan, Y. Kaufman, T. Nakajima, F. Lavenu, and I. Jankowiak. 1997. Automatic Sun and Sky Scanning Radiometer System for Network Aerosol Monitoring. Accepted for publication in *Rem. Sens. of Environ*.

Nakajima, T., M. Tanaka, and T. Yamauchi. 1983. Retrieval of the optical properties of aerosols from aureole and extinction data. *Appl. Opt.,* 22, 2951 - 2959.