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Nephelometer Instrument Handbook

J Uin

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ARM

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J Uin, Brookhaven National Laboratory

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Acronyms and Abbreviations

AOS	Aerosol Observing System
ARM	Atmospheric Radiation Measurement
HEPA	high-efficiency particulate air
MAOS	Mobile Aerosol Observing System
PMT	photomultiplier tubes
RH	relative humidity
UTC	Coordinated Universal Time

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1.0 Instrument Title

The TSI model 3563 integrating nephelometer instrument is pictured in section 4.0, and more information can be found on the manufacturer's website.

2.0 Mentor Contact Information

Janek Uin
Environmental and Climate Sciences Department
Brookhaven National Laboratory
Building 815 E
Upton, New York 11973
Phone: (631) 344-3612
E-mail: juin@bnl.gov

3.0 Vendor/Developer Contact Information

TSI Incorporated
500 Cardigan Road
Shoreview, Minnesota 55126
FAX: +1 (651) 490-3824
E-mail: particle@tsi.com

4.0 Instrument Description

The integrating nephelometer (Figure 1) is an instrument that measures aerosol light scattering. It measures aerosol optical scattering properties by detecting (with a wide angular integration – from 7 to 170°) the light scattered by the aerosol and subtracting the light scattered by the carrier gas, the instrument walls, and the background noise in the detector (zeroing). Zeroing is typically performed for five minutes every day at midnight UTC. The scattered light is split into red (700 nm), green (550 nm), and blue (450 nm) wavelengths and captured by three photomultiplier tubes. The instrument can measure total scatter as well as backscatter only (from 90 to 170°) (Heintzenberg and Charlson 1996, Anderson et al. 1996, Anderson and Ogren 1998, TSI 3563 2015).

At the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility, prior to 2024 two identical nephelometers were run in series with a sample relative humidity (RH) conditioner between them, forming the humidigraph instrument. This was possible because nephelometer sampling is non-destructive and the sample can be passed on to another instrument. The sample RH conditioner scanned through multiple RH values in cycles, treating the sample. This kind of setup allowed study of how aerosol particles' light scattering properties are affected by humidification (Anderson et al. 1996). For historical reasons, the two nephelometers in this setup were labeled "wet" and "dry", with the "dry" nephelometer usually being the one before the conditioner and sampling ambient air (the names are switched for the Mobile Aerosol Observing System (MAOS) measurement site due to the high RH of the ambient air). Since 2024, all ARM humidigraph instruments were removed from service and only single nephelometers were retained at each site without active RH conditioning (except drying the sample flow before the Aerosol Observing System (AOS) impactor – see the ARM impactor handbook).

Figure 1. The TSI model 3563 integrating nephelometer. ARM image.

5.0 Measurements Taken

The main measurement outputs of the nephelometer are the aerosol particle optical scattering coefficients (total scatter and backscatter) for three wavelengths (700, 550, and 450 nm). Additional measurements include sample time, sample air pressure, sample RH, and sample temperature.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

The data from the nephelometer are recorded in plain text in column format with appropriate headers specifying the data. The recorded data fields include (customizable by the user):

> Measurement date/time, sample pressure, sample RH, sample temperature, raw photon counts from different operating modes, scattering coefficients for the three wavelengths from different operating modes (total scatter, backscatter, and zero mode), current operating mode, lamp voltage and current, instrument status flags.

Output data are recorded after every sample, typically every five seconds (depends on the averaging time). A new data file is started every hour and every time the system is restarted.

6.2 Data Ordering

Data from the nephelometer can be ordered from http://www.arm.gov/instruments/nephelometer. Data are organized by measurement location/campaign.

6.3 Data Plots

Figures 2 and 3 show typical data for the nephelometer. Only the data from the "dry" nephelometer are shown because the data for "dry" and "wet" instruments are similar. Figure 2 shows measured aerosol optical total scatter and backscatter coefficients as a function of time (and the state of the impactor at the inlet of the external sampling system). Figure 3 shows meteorological parameters as measured by the nephelometer. The ~10 hPa "jumps" in ambient pressure are due to the impactor on the external sampling system switching states and can be used to verify the proper operation of the external impactor valve. These plots were generated using the ARM user facility Data Quality Diagnostic Plot Browser (http://plot.dmf.arm.gov/plotbrowser/).

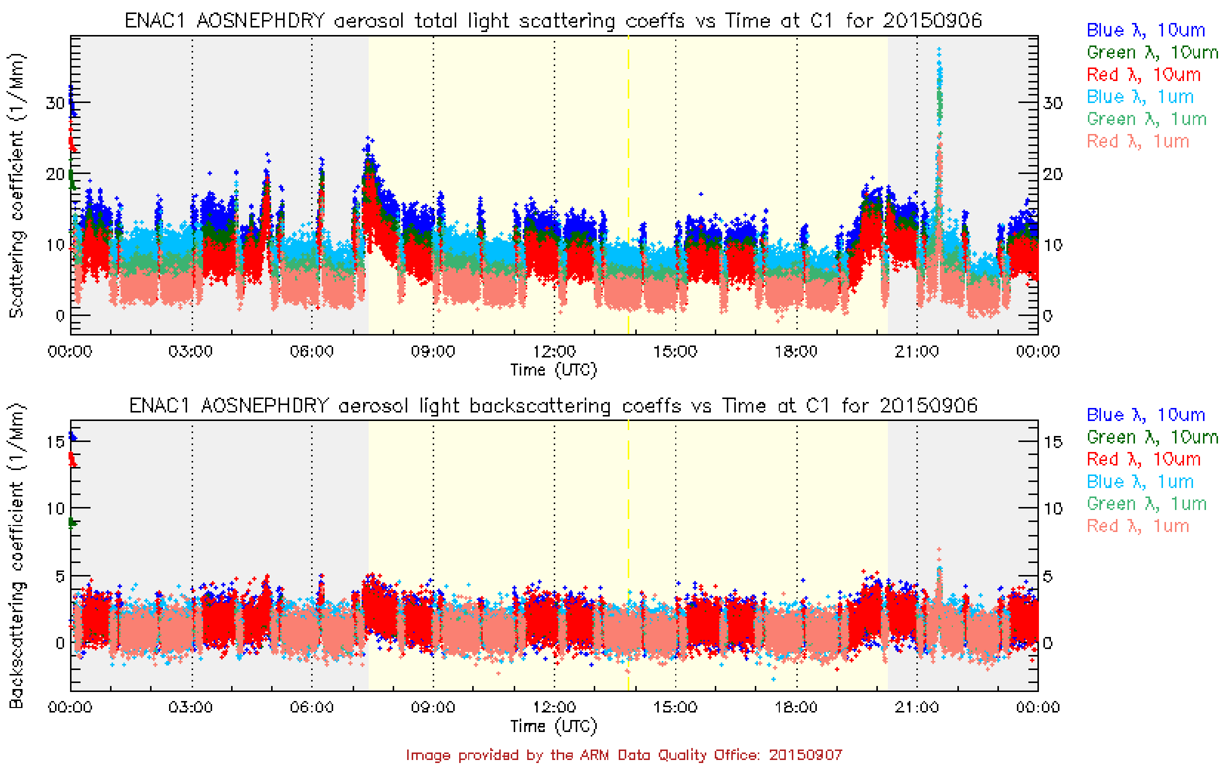

Figure 2. Aerosol optical scattering coefficients (total scatter and backscatter for three wavelengths and for two different states of the impactor at the inlet of the external sampling system) as measured on September 6, 2015 by the nephelometer deployed at the Eastern North Atlantic site on Graciosa Island, Azores, Portugal.

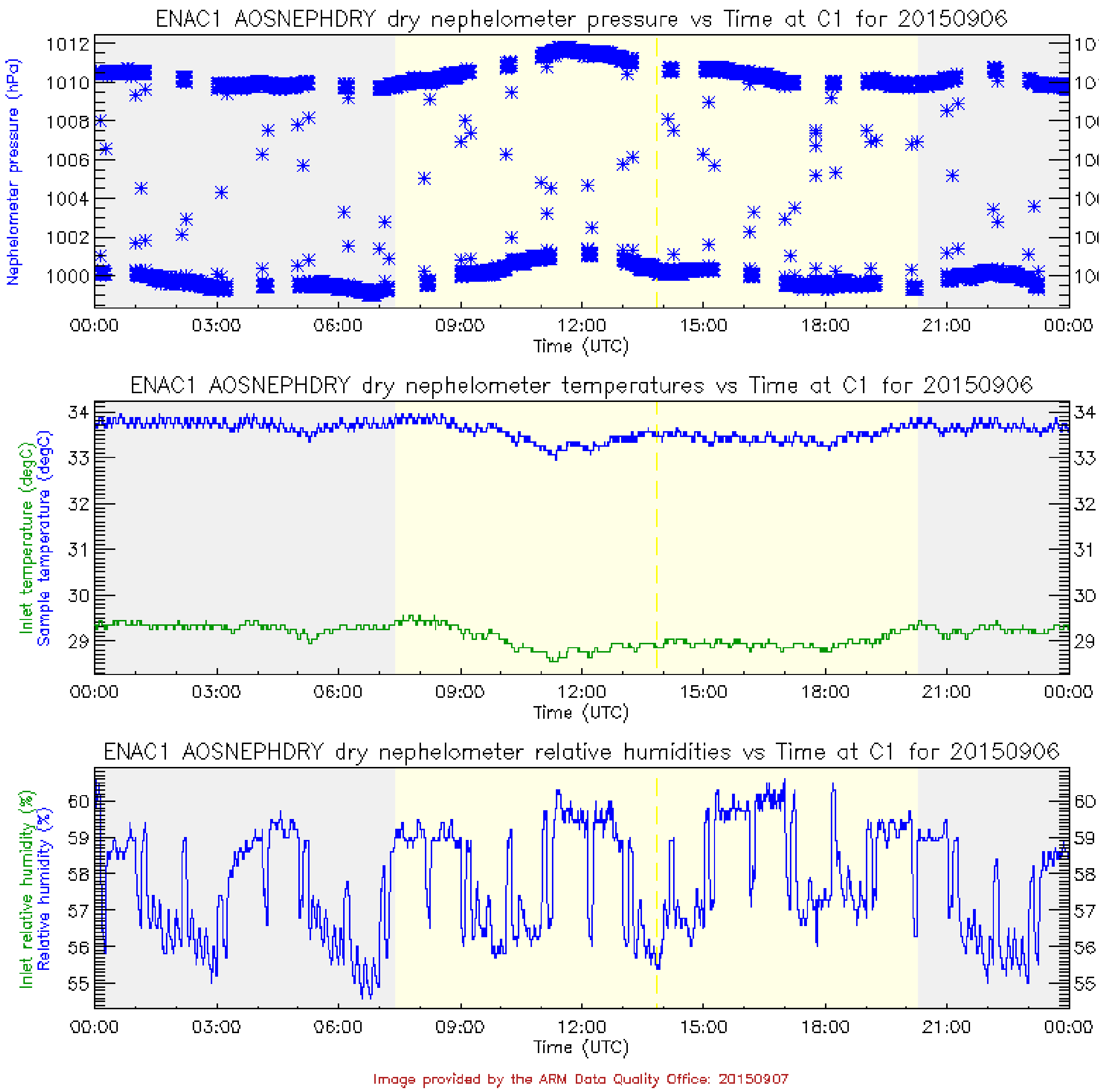

Figure 3. Meteorological parameters (pressure, RH, temperature) as measured by the nephelometer on September 6, 2015 at the Eastern North Atlantic site on Graciosa Island, Azores, Portugal.

6.4 Data Quality

Data quality evaluation involves automatic flagging of data based on criteria developed by instrument mentors and automatic generation of plots in collaboration with the ARM Data Quality Office.

Automatic data quality checks include:

Checking the “mode” variable in the nephelometer data to see in which operating mode the instrument is (normal, zeroing) and flagging the data accordingly.

Automatically generated plots include (see also Figure 2 and Figure 3):

Scattering coefficients and sample pressure. Both should show periodic high and low values corresponding to the different states of the external impactor at the sample inlet. Also, scattering should usually be highest for blue (450) and lowest for red (700) light. (There are exceptions, though, and for some measurement sites, such as those with marine influences, the red scattering coefficient can instead be the highest at 10 µm external impactor cut size.)

6.5 Calibration Data Base

Nephelometer calibration involves measuring the scattering coefficients of dry CO_2 gas introduced into the system and comparing them with known values from literature that are adjusted for calibration conditions (temperature, RH, air pressure) (Anderson et al. 1996).

During deployment, calibration is typically performed by instrument mentors or site operators at least once every 12 months. Calibration coefficients are recorded by ARM.

7.0 Technical Specification

7.1 Units

Aerosol particle optical scattering coefficient: inverse meters (m-1); RH: % (dimensionless), air pressure: hectopascals (hPa), temperature: kelvins (K).

7.2 Range

Upper detection limit for aerosol optical scattering coefficients is 2×10^{-2} m^{-1}. Lower limit is defined by instrument sensitivity (depends on measurement averaging time) which is between 1×10^{-7} and 3×10^{-7} m^{-1} (depending on the wavelength) for 30-second averaging time.

Angular integration of scattered light is from 7 to 170° in total scatter mode and from 90 to 170° in backscatter mode.

7.3 Accuracy

Accuracy of optical scattering coefficient measurements depends on the accuracy of nephelometer calibration with CO_2 gas and the instrument's internal non-idealities, with the latter being the dominant factor. In general, the accuracy is within ±10% (Anderson et al. 1996).

For certain applications, an additional source of measurement error must be considered. This is the angular truncation error, which comes from the nephelometer's limited angular integration range of 7 to 170° (Anderson and Ogren 1998). The truncation error is 5-10% for submicron particles and 30-50% for particles with sizes between 1 and 10 µm.

7.4 Repeatability

Based on experimental comparison of several nephelometers, the repeatability of aerosol optical scattering coefficient measurements is within ±1% (Anderson and Ogren 1998).

7.5 Sensitivity

Aerosol optical scattering coefficient measurements are sensitive to sample pressure and humidity (Anderson et al. 1996, Anderson and Ogren 1998). No automatic corrections are applied by the instrument and care should be taken when comparing measurement results from different times and locations.

7.6 Uncertainty

For low particle concentrations or short sampling times, random noise is the dominant source of nephelometer uncertainty (Anderson et al. 1996). For typical operating conditions, the detection limits for 30-second averages are between 1×10^{-7} and 3×10^{-7} m^{-1} (depending on the wavelength).

For particle scattering coefficients above about 10^{-6} m^{-1} and averaging times longer than about 60 seconds, systematic rather than random sources of uncertainty become dominant. These divide into gas-calibration uncertainties, which are independent of particle size, and uncertainties due to wavelength and angular non-idealities, which are strongly size dependent. The gas calibration contributes about a ±1% uncertainty to particle scattering measurements. The dominant cause is uncertainty in the scattering coefficient of the calibration CO_2 gas. A larger source of systematic uncertainty stems from non-idealities in the wavelength and angular sensitivities of the nephelometer. Based on modeling and experimental results, the systematic uncertainty is within ±10% (Anderson et al. 1998).

7.7 Input Values

The user can set the nephelometer measurement schedule, which includes operating modes (total scatter and backscatter, different zero measurement modes) and their durations.

7.8 Output Values

The recorded data include:

> Measurement date/time, sample pressure, sample RH, sample temperature, raw photon counts from different operating modes, scattering coefficients for the three wavelengths from different operating modes (total scatter, backscatter, and zero mode), current operating mode, lamp voltage and current, instrument status flags.

8.0 Instrument System Functional Diagram

The main components of the instrument are shown in Figure 4 (Anderson et al. 1996). See measurement theory below for details.

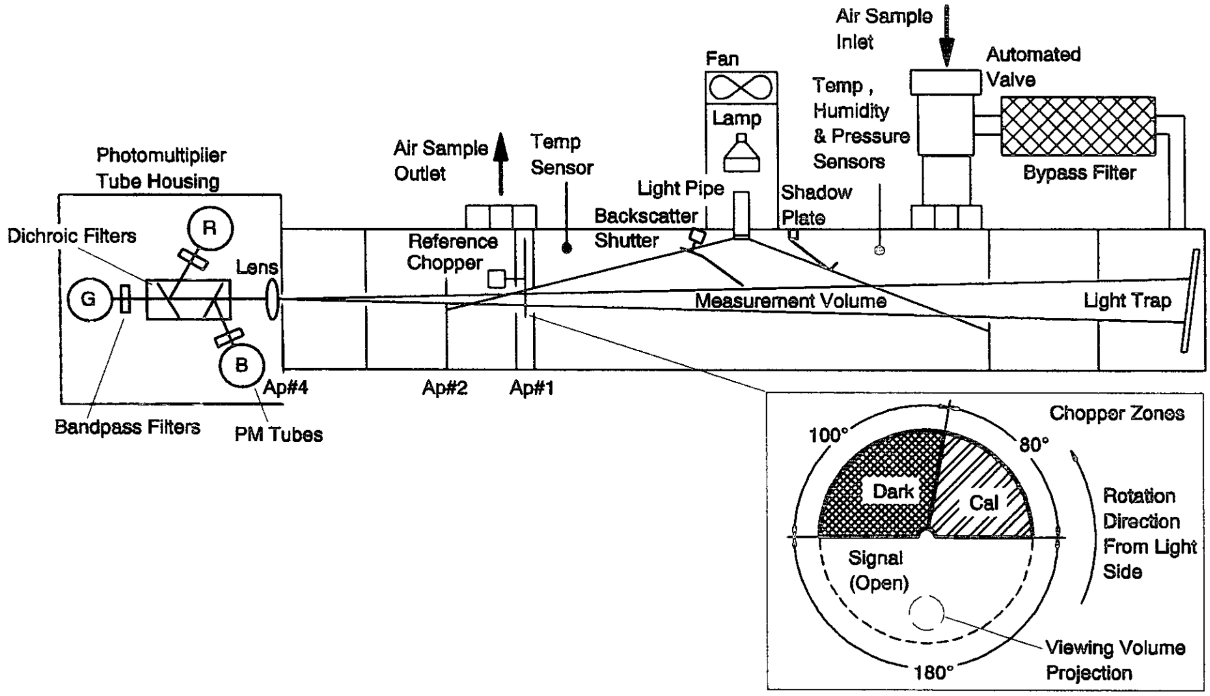

Figure 4. Nephelometer functional diagram (Anderson et al. 1996).

9.0 Instrument/Measurement Theory

An internal small turbine blower or an external flow system draws an aerosol sample through the large-diameter inlet into the measurement volume (Figure 4). There, the sample is illuminated over an angle of 7 to 170° by a halogen lamp directed through an optical light pipe and opal glass diffuser. The sample volume is viewed by three photomultiplier tubes (PMT) through a series of apertures set along the axis of the main instrument body. Aerosol scattering is viewed against the backdrop of an efficient light trap. The light trap, apertures, and a highly light-absorbing coating on all internal surfaces of the instrument combine to give a low scatter signal from the walls of the instrument.

Dichroic filters, in front of the PMT tubes, split and direct the light, which has been scattered by aerosol. The light is directed into three bandpass filters, blue (450 nm), green (550 nm), and red (700 nm). A constantly rotating reference chopper has separate areas to provide three types of signal detection. The first area gives a measure of the aerosol light scattering signal allowed by an opening in the rotating chopper. The second area blocks all light from detection and gives a measurement of the PMT dark current, which is subtracted from the measurement signal. The third area is a translucent portion of the chopper, illuminated by the halogen lamp, which provides a measure of the light-source signal. In this way, over time, any change in the light source or in detector efficiency is compensated.

In backscatter mode, the backscatter shutter rotates under the lamp to block light in the 7 to 90° range. When light is blocked, only light scattered in the backward direction is transmitted to the PMT detectors. The backscatter signal can be subtracted from the total signal to calculate forward-scattering signal data. When this measurement is not of interest, the backscatter shutter can be “parked” in the total scatter position. Periodically (typically for five minutes every midnight UTC), an automated valve built into the inlet is activated to divert the entire aerosol sample through a high-efficiency particulate air (HEPA) filter. This gives a measure of the clean-air signal for the local environment. This signal is subtracted, along with the PMT dark current signal, from the aerosol-scatter signal to give only that portion of the scatter signal provided by the sample aerosol. Particle scattering parameters for all three wavelengths of total and backscatter signal are continuously averaged and passed to a computer for permanent storage.

10.0 Setup and Operation of Instrument

1. Connect the external power supply to the instrument (for initial setup only).
2. Connect the nephelometer to a measurement control computer via a serial cable (for initial setup only).
3. Switch on the instrument and the measurement control computer. The control software running on the measurement control computer should start automatically.
4. Make sure the external sample flow system is set to draw 7.5 lpm through the nephelometer.
5. The instrument is now ready to operate automatically.

11.0 Software

Instrument control and data acquisition is performed by NI LabView-based software written by Brookhaven National Laboratory.

12.0 Calibration

The nephelometer is calibrated by the manufacturer before delivery to the user and during instrument maintenance at the manufacturer's facilities. Instrument mentors or site operators perform calibration during deployment, typically at least once every 12 months and as needed (e.g., before a new deployment).

Nephelometer calibration involves measuring the scattering coefficients of dry CO_2 gas introduced into the system and comparing them with known values from literature that are adjusted for calibration conditions (temperature, RH, air pressure) (Anderson et al. 1996). Calibration coefficients can be applied to raw measurement data.

13.0 Maintenance

Action (when)

- Replacing the halogen lamp (when visual inspection or the software status indicates a lamp failure).
- Replacing the internal HEPA filter (when discoloration in the tubes connected to the HEPA filter indicates water in the system). This is especially relevant in humid measurement locations.

14.0 Safety

The nephelometer contains a high-voltage source for the photomultiplier tubes. During normal operation, the user is not exposed to high voltages.

The nephelometer halogen lamp housing may reach temperatures high enough to cause burns. Disconnect power to the nephelometer and allow the halogen lamp and the lamp housing to cool before handling.

15.0 Citable References

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