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DAQ-07-001.2 Standard Operating Procedure (SOP) Vaisala CL-51 Ceilometer OPERATOR RESPONSIBILITIES

Revision 2



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1.0 Approval Sign Off-Sheet

I certify that I have read and approve of the contents of the Vaisala CL-51 Ceilometer Operator Responsibilities Standard Operating Procedure with an effective date of November 15th, 2021.

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Disclaimer: This document, and any revision hereto, is intended solely as a reference guide to assist individuals in the operation of the instrument, related to the North Carolina Division of Air Quality's Ambient Monitoring Program.

SOP Acronym Glossary

AQS – Air Quality System (EPA's Air database)

ARM – (Envista) Air Resources Manager

As – Arsenic

ASCII – American Standard Code for Information Interchange

DAQ – North Carolina Division of Air Quality

DIT – North Carolina Department of Information Technology

DNS – Domain name system

EPA – United States Environmental Protection Agency

ft - feet

Ga - Gallium

gal – gallon

GPS – Global positioning system

In – Indium

IP – Internet Protocol

LAB – Laboratory Analysis Branch

LASER – Light amplification by stimulated emission of radiation

LED – Light emitting diode

LIDAR – Light distance and ranging

NC – North Carolina

netCDF – Network common data form

m – meter

MLH – Mixing layer height

mm - millimeter

PAMS – Photochemical assessment monitoring station

PBL – Planetary Boundary layer

PC – Personal Computer

PDF – portable document format (.pdf)

POST – Power on self-test

SOP – Standard operating procedure

TCP – Transmission Control Protocol

UCN – Unified Ceilometer Network

UMBC – University of Maryland Baltimore County

UTC – Coordinated Universal Time

WAN – Wide area network

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2.0 SCOPE AND PURPOSE

The scope and purpose of this standard operating procedure (SOP) is to describe the steps required to successfully install, operate, collect, review, and transmit data associated with the North Carolina Division of Air Quality (DAQ) photochemical assessment monitoring station (PAMS) Vaisala CL-51 ceilometer. The ceilometer measures the planetary boundary layer (PBL) and mixing layer height (MLH) using a pulsed indium-gallium-arsenic (InGaAs) diode light amplification by stimulated emission of radiation, LASER, at 910 nanometers. The ceilometer is a pulsed light distance and ranging (LIDAR) source operating at a fixed wavelength. The ceilometer measures the backscattered radiation profile via interactions of light and aerosols in the atmosphere in a variety of metrological conditions. The backscattered radiation profile provides the altitude of aerosol mixing as well as cloud heights. The ceilometer is located at the Millbrook site at 3801 Spring Forest Road in Raleigh, North Carolina (NC). This PAMS site is used to monitor the metropolitan statistical area air-shed of Raleigh.



Figure 1: Vaisala CL-51 Ceilometer

In partnership with the Unified Ceilometer Network (UCN), hosted by the University of Maryland Baltimore County (UMBC), the DAQ reports PAMS MLH data to the United States Environmental Protection Agency (EPA) (for more information refer to Appendix A). UCN data are reduced by an automated data analysis protocol developed by atmospheric LIDAR researchers and is peer reviewed. Data are available at <https://www.ucn-portal.org/>.

UNIFIED CEILOMETER NETWORK



Maryland
Department of
the Environment



Figure 2: UCN Interagency Partnerships

3.0 EQUIPMENT CHECKS AND MATERIALS

This section describes the equipment materials that are required to complete the steps described in this document. Additional subsection(s) or SOPs will also describe the equipment and materials as needed.

3.1 Equipment and Material List

- Vaisala CL-51 ceilometer
- Vaisala CL-51 optical termination hood
- Personal computer (PC) with Windows 10 operating system equipped with:
 - Secure internet access to the State of NC wide area network (WAN)
 - BL-View software (version 2.1.2 or newer)

- MOXA N-Port Administrator
 - Microsoft Office 365 suite
 - Adobe Portable Document Format (PDF) Reader
 - Putty terminal client
 - Python (version 3.9.6 or newer)
 - Google Chrome or equivalent web browser
 - Envista Air Resources Manager (ARM)
 - 2 Terabyte external backup hard drive or equivalent server environment
 - ~150 feet (ft) of shielded Ethernet cable
 - Gigabit Switch
- Concrete pad (for instrument mounting)
- Hand Tools:
 - Drill with masonry 5/8 in drill bit (for installation only)
 - 1 1/16 in Wrench (for installation only)
 - Phillips head screwdriver
 - Flat head screwdriver
 - 3 millimeter (mm) and 4mm hex-key
 - ½ in nut driver
 - Hammer
 - 125-foot Fishing Tape
- 3x DeWalt 5/8 in by 6 in Power stud HD5 concrete anchor bolts (for installation only)
- 10-gauge copper wire
- 5/8 in bronze grounding clamp
- Galvanized grounding rod
- 10-gauge ring wire connector
- Zip-Ties
- Personal Protective Equipment
 - Steel-toe nonslip shoes or boots
 - Gloves
 - Textured grip, heat resistant work gloves
 - Nitrile gloves
 - Safety glasses: prescription or impact resistant are acceptable
- Cleaning Supplies:
 - Mild Detergent or Windex
 - Lint-free microfiber cloths
 - Clean water
 - 3-gallon (gal) plastic bucket
 - Shop-vacuum

3.2 Support Equipment Checks

3.2.1 Heater and Blower Checks

- Occurs automatically during ceilometer boot up after 5 minutes.
- Results of this check are available 5 minutes after starting the unit and are indicated by the **CLB OK** light emitting diode (LED) if you are present at the site and looking at the instrument board as shown in Figure 2. The results of the test are also displayed in the status messages in the BL-View software.

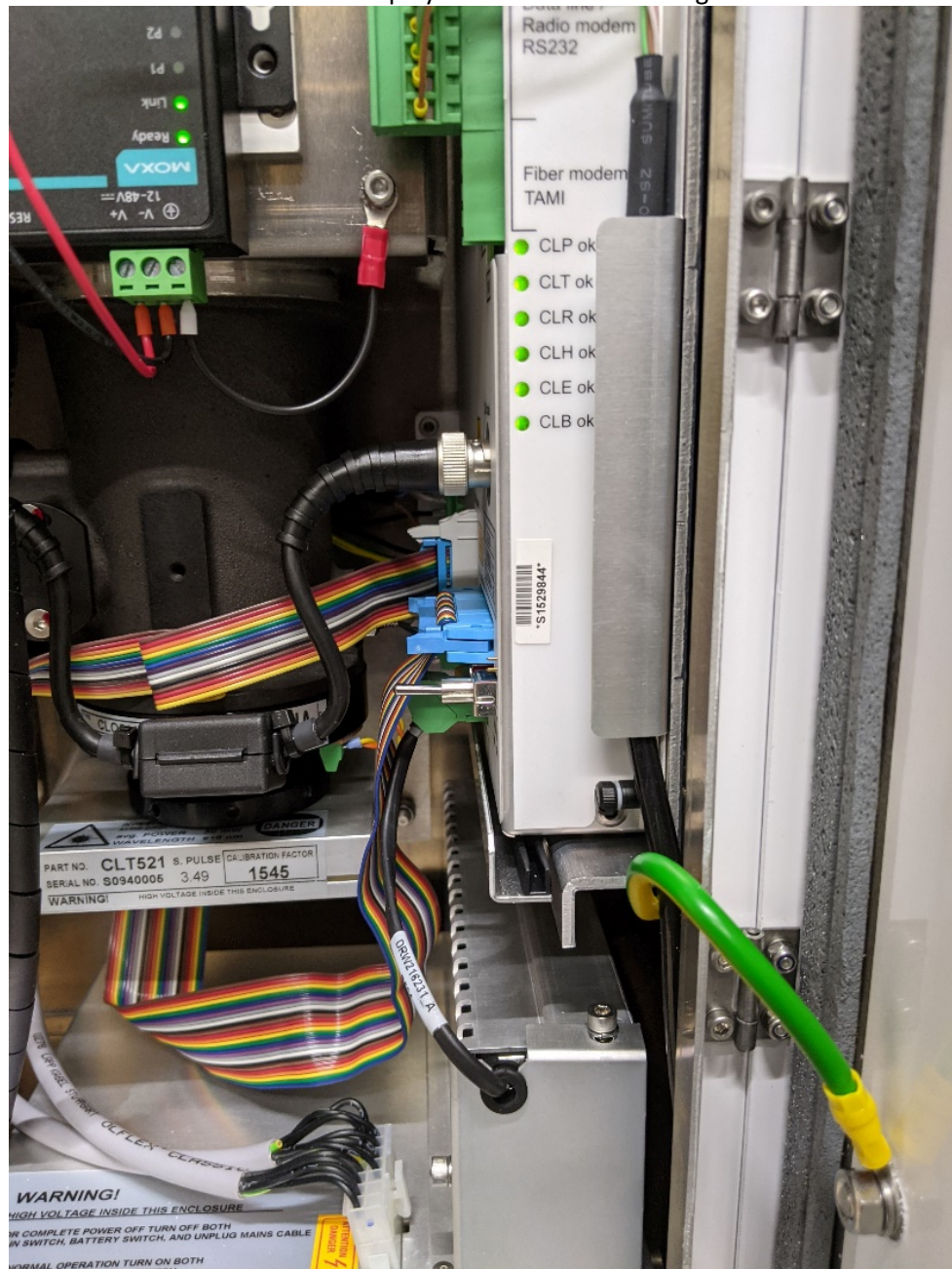


Figure 3: Vaisala CL-51 Ceilometer POST LED Display

3.2.2 Routine System Diagnostic Check

- Operator must check system alarm and warning messages routinely on workdays.

- Alarms are shown in the BL-View software under the **Alerts** tab and use the following three characters to indicate status:
 - 0** – self-check OK [boot only]
 - W** – At least one warning active, no alarms
 - A** – At least one alarm active

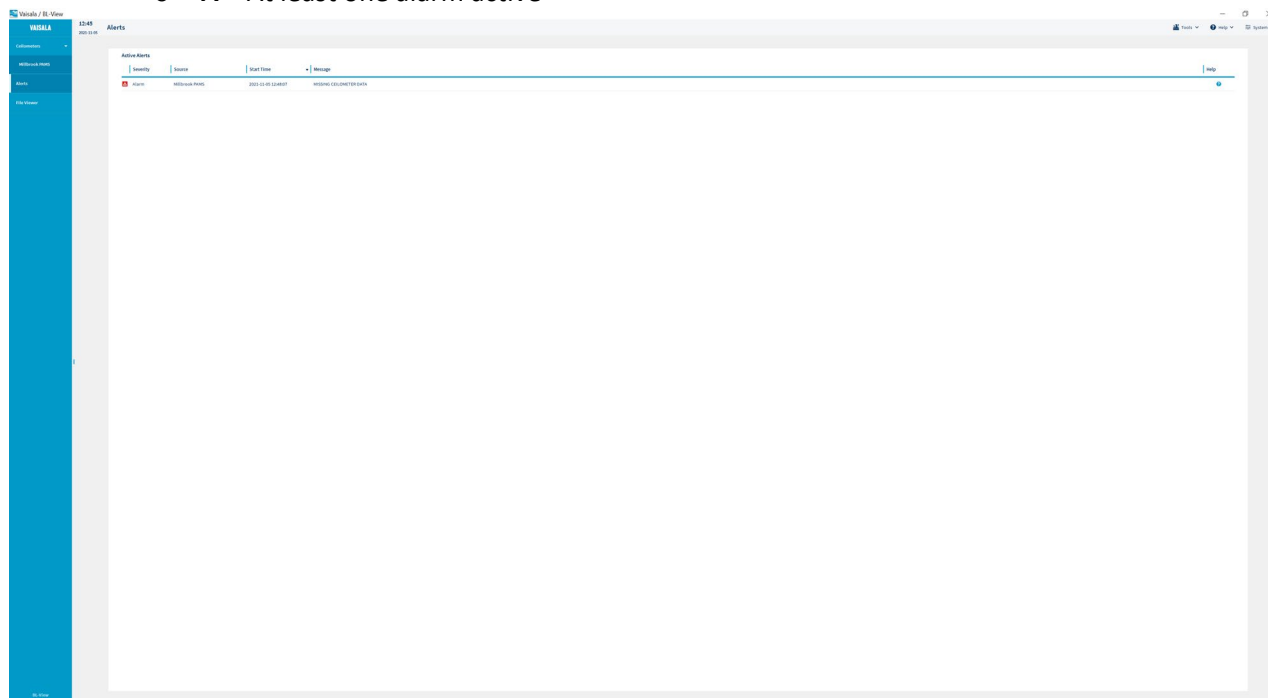


Figure 4: Vaisala BL-View Alerts Software Display

- See Appendix B for details of warnings and alarm messages, section 5.2 for BL-View operation and section 9 for corrective actions.
- A blank alerts screen denotes that the system is functioning without any reported errors.

4.0 SITE CHECKS

4.1 Daily Operator Check

- Each workday the operator must remotely connect or physically visit the site to verify the instrument is operational. Any anomalous operation must be recorded in the ceilometer logbook and rectified in a timely manner.
- Verify the computer date and time are correct. If not, see section 9.6 for correction. DAQ does not correct for daylight savings time and special care should be taken when daylight savings begins and ends. Special IT policy is in place to prevent system time changes, but site operators should check the systems when these events occur.
- Conduct the routine system diagnostic check in section 3.2.2.

4.2 Site Visit Checklist

- 1 Each time the operator visits the site the following must occur:
- 2 Inspect the CL-51 window if it is dirty, see section 9.2 for corrective action
- 3 Inspect the door gasket: check that the gasket and its contact surfaces are free of debris and in good condition. If it not, see section 9.3 for corrective action
- 4 Examine all site power connections and conditions. Document any outages in the site electronic logbook.
- 5 Inspect the backup battery for signs of bulging, residue near the battery vent, leaking electrolyte or corroded terminals. See section 9.4 for corrective action.
- 6 Conduct the routine system diagnostic check in section 3.2.2.
- 7 Inventory the supplies at the site, make sure the materials required for regular upkeep are kept within the Millbrook shelter.
- 8 Record any observations into the ceilometer logbook.

4.3 Semi-Annual Instrument Performance Check

- 1 Every six months, or sooner if desired, place the optical termination hood on the ceilometer and allow it to equilibrate for at least an hour.
- 2 View the backscatter profile in BL-View and confirm that there is minimal scatter detected as shown below:

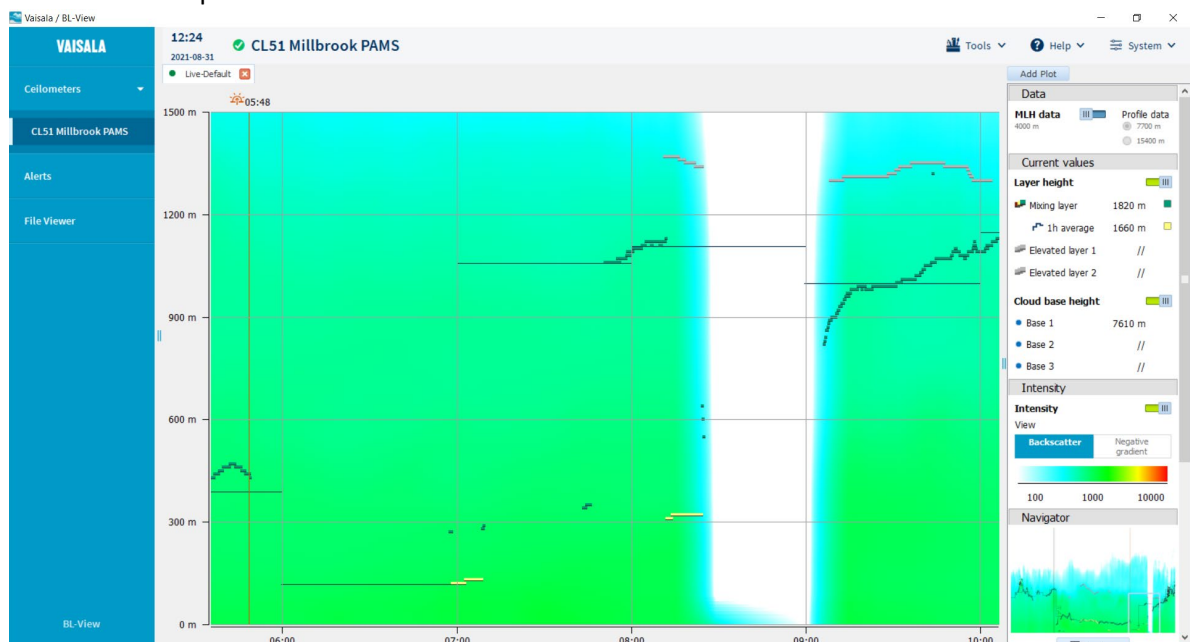


Figure 6: Vaisala CL-51 Ceilometer Instrument Performance Check

- 3 Record the results of the instrument performance check into the ceilometer logbook.

5.0 DETAILED PROCEDURES

5.1 Ceilometer Initial Installation and Configuration

- 1 Prior to installation at the Millbrook site, unpack the ceilometer. Save all original shipping materials for transport to the Millbrook monitoring site.
- 2 Open the two black locking switches on the left of the ceilometer to open the door. The instrument will open exposing the window and internals housing as shown in Figure 6:



Figure 6: Vaisala CL-51 Ceilometer Instrument Window and Internals Housing

3 Connect external cables for power and data communications: port J1 is used for the window blower, port J2 is used for electrical power connection, port J3 is used for remote communications and port J4 is used for local maintenance and should be capped when not in use. A breakdown of these connections and their respective pin functions are shown below in Figure 7:

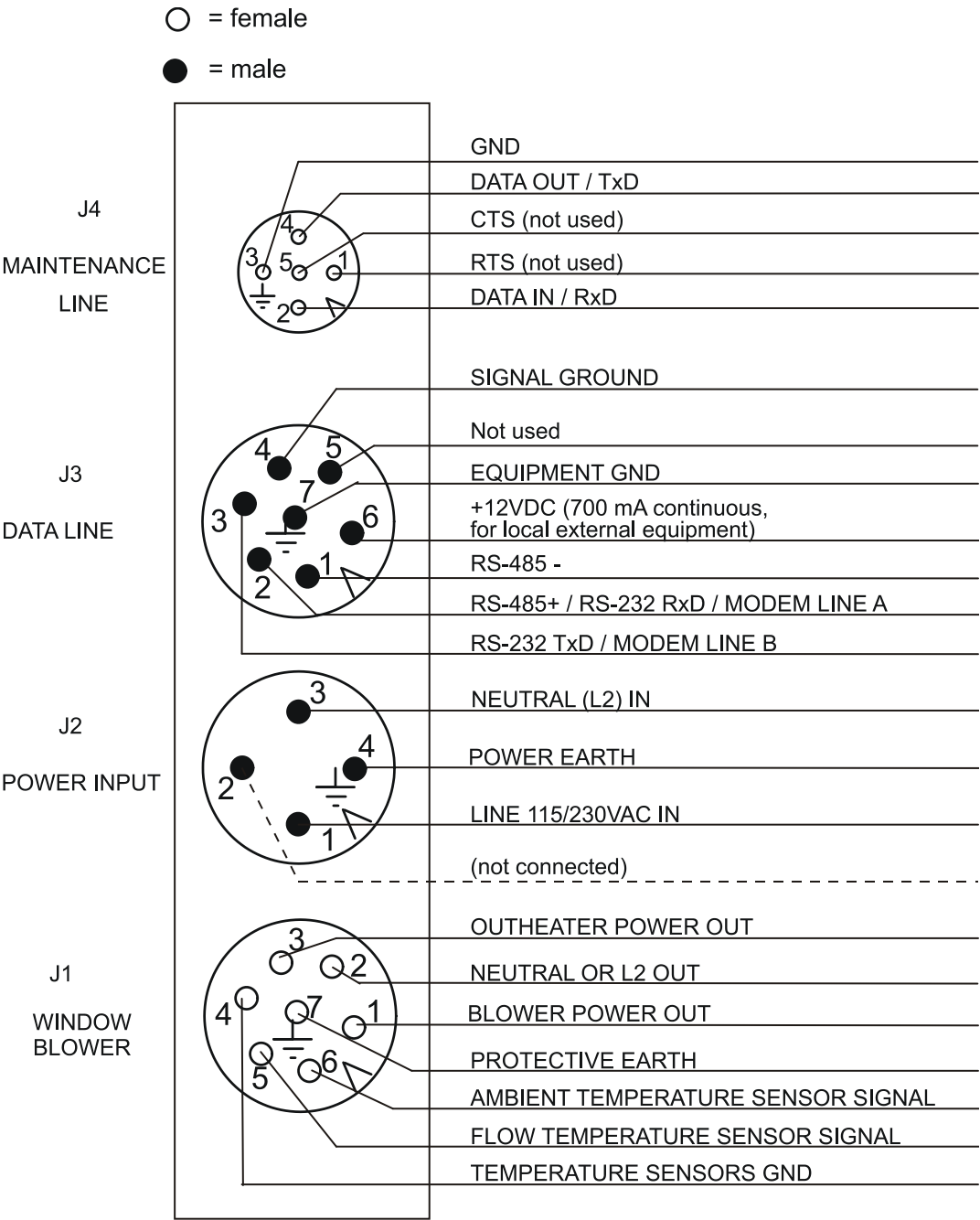


Figure 7: Vaisala CL-51 Ceilometer External Cable Connections

4 Connect the ceilometer to the PC computer with the 25 meter (m) shielded Ethernet cable. The ceilometer data port is located behind and to the left of the J1 port connector. It is protected with a weather-tight metal cap.

Loosen the cap with your fingers and connect the end of the Ethernet cable with a black screw fitting to the ceilometer data port. Screw the fitting into place to make a good weather-tight seal.

- 5 While wearing nitrile gloves, remove the yellow protective covering from the laser window.
- 6 Expose the instrument internals by opening the three black caps and rotating the screw counterclockwise with a flathead screwdriver. The instrument internals are shown below in Figure 8:

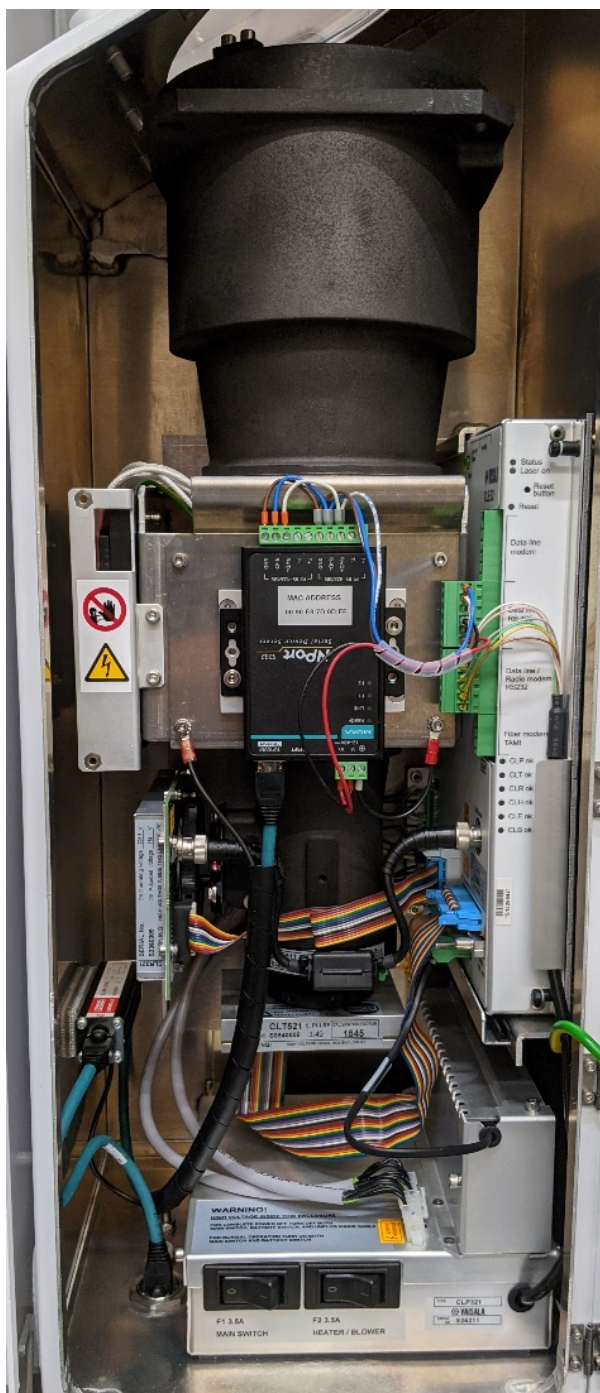


Figure 8: Vaisala CL-51 Ceilometer Instrument Internals

- 7 If you are inside, install the CL-51 optical termination hood on the ceilometer window as shown below in Figure 9. This is done to protect the detector and prevent oversaturation that could damage the equipment. This device simulates a cloudless day with infinite visibility. No BLs will be observed while operating the ceilometer with the optical termination hood equipped.

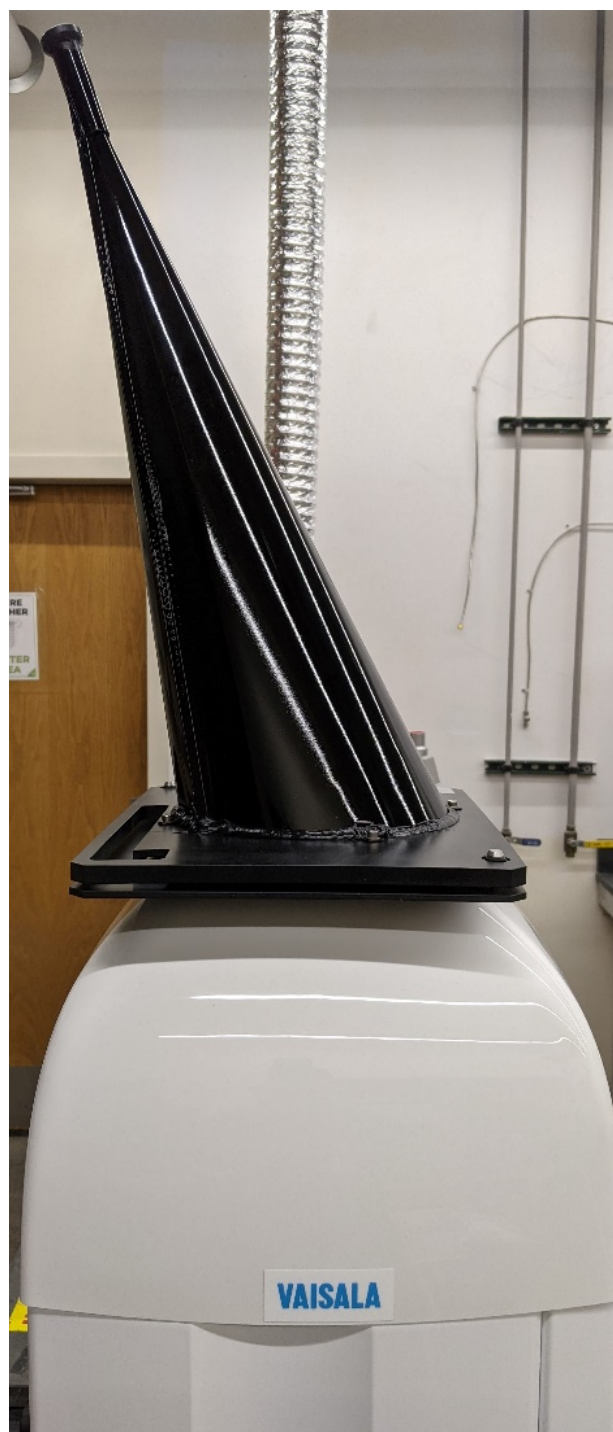


Figure 9: Vaisala CL-51 Ceilometer with Optical Termination Hood Installed

- 8 Switch the main circuit breaker, heater blower breaker and battery backup switch to the on position and close instrument internals and housing. They are shown circled in red in Figure 10:

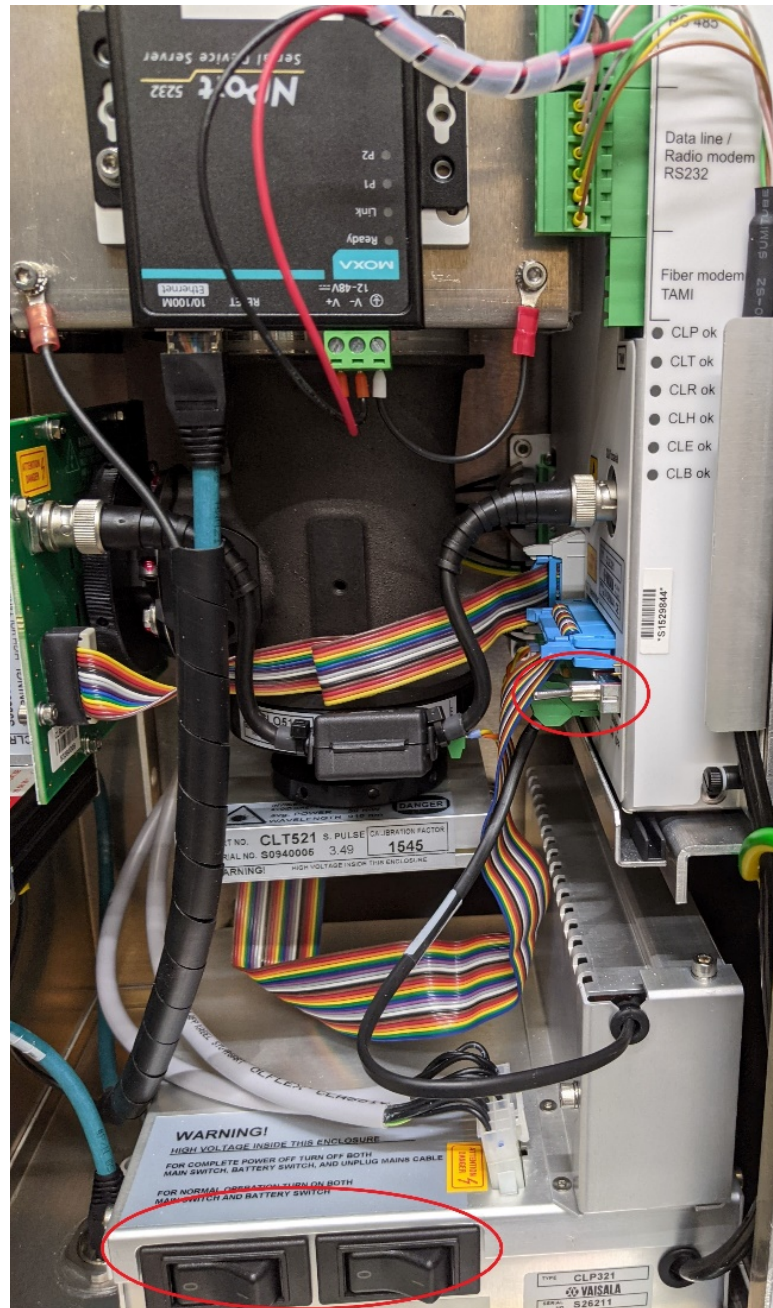


Figure 10: Vaisala CL-51 Ceilometer Main Circuit Breaker, Heater/Blower Circuit Breaker and Battery Switch Circled in Red

- 9 Establish a plug-and-play connection with the BL-view software and the ceilometer by logging into the PC and launching BL-View.
- 10 In BL-View, open settings and set the ceilometer location to the PAMS-Millbrook site, located at 35.85611 latitude and -78.57417 longitude Global Positioning System (GPS) coordinates with a 100m above sea level

altitude. Set the Coordinated Universal Time (UTC) offset to -5 for eastern standard time. This will set local sunrise and sunset times for the ceilometer. **Note: DAQ does not change PC time to observe daylight savings on ambient monitoring equipment.** The settings for the ceilometer are shown in Figure 11:

BL-View - Settings

Display | Presets | Devices

CL51 Millbrook PAMS

Device

Device Name: CL51 Millbrook PAMS

Latitude: 35.8561
Give the coordinates according to the standard WGS84
-90.0000 ... 90.0000 degrees south, north

Longitude: -78.5742
-180.0000 ... 180.0000 degrees west, east

Altitude: 100 m

UTC offset: UTC -05:00

WMO station number: (Optional)

Data

File suffix: PAMS_NCDEQ
(Optional) You can define text that is added to the end of netCDF file names.

File path: C:\BLViewData Browse

Connection

Select the settings for communicating with the device. The values must match the settings in the device.

Connection type: ☒ Serial
☐ UDP
☐ TCP Server
☐ TCP Client

Baud rate: 19200

Serial port number: COM1

Data bits: 8

Stop bits: 1

Parity: None

Messages

Select the device data message settings. The values must match the settings in the device.

Message type: msg1_10x1540
Recommended values:
CL31:msg2_10x770 / CL51:msg2_10x1540
If the Sky Condition algorithm is disabled:
CL31:msg1_10x770 / CL51:msg1_10x1540

Message interval: 36 s (2...75)

Add Delete Save Cancel Close

License: 1/1 Devices added

Figure 11: Vaisala BL-View Ceilometer Initialization Setting Configuration

- 11 Next, plug in the PC ethernet cable and allow it to establish a connection to the state WAN. Securely connect and obtain the static Internet Protocol (IP) address, subnet mask, and gateway IP of the WAN router internal IP network. To obtain the subnet mask and gateway IP, open a command prompt and type ipconfig.
- 12 Reprogram the MOXA device with the new static IP and subnet from the WAN router. To begin, open google chrome and type **192.168.127.254** into the address bar. Securely login to the MOXA controller.
- 13 On the left-hand side of the screen select network settings. The current settings will populate as shown below:

Figure 12: MOXA NPort Manager Network Settings

- 14 Replace the static IP, subnet mask, and gateway obtained from step 11. Click submit. No domain name system (DNS) server is required.
- 15 In the Moxa main menu, navigate to the operating settings and click the plus sign to expand. Select Port 1 and the screen below in Figure 13 will appear:

Figure 13: MOXA NPort Manager COM Operating Settings for Port 1

- 16 Click the drop-down arrow in operation mode next to **Real COM Mode** and select **TCP Server Mode**. The screen will change and populate as shown in Figure 14:

MOXA www.moxa.com

Operating Settings

Port 01

Operation mode: TCP Server Mode

TCP alive check time: 7 (0 - 99 min)

Inactivity time: 0 (0 - 65535 ms)

Max connection: 1

Ignore jammed IP: ☐ No ☐ Yes

Allow driver control: ☐ No ☐ Yes

Data Packing

Packing length: 0 (0 - 1024)

Delimiter 1: 0 (Hex) ☐ Enable

Delimiter 2: 0 (Hex) ☐ Enable

Delimiter process: Do Nothing (Processed only when Packing length is 0)

Force transmit: 0 (0 - 65535 ms)

TCP Server Mode

Local TCP port: 4001

Command port: 966

☐ Apply the above settings to all serial ports (Local listen port will be enumerated automatically).

Submit

Figure 14: MOXA NPort Manager TCP Server Operating Settings for Port 1

- 17 Change the TCP port to the secure port provided by the Vaisala.
- 18 Make the same changes for port 2 as done to port 1 except use the other port number provided by Vaisala. The port 1 and port 2 TCP ports must be different. Click submit when finished.
- 19 Click save in the MOXA main menu and exit. The MOXA programming is now complete.
- 20 On the ceilometer PC open the Network Connections screen. Right click on the Ethernet icon in the bottom right corner of the desktop select **open network and internet settings**.
- 21 Click on change adapter options.
- 22 Right click on the Ethernet connection and select properties. The following screen will appear:

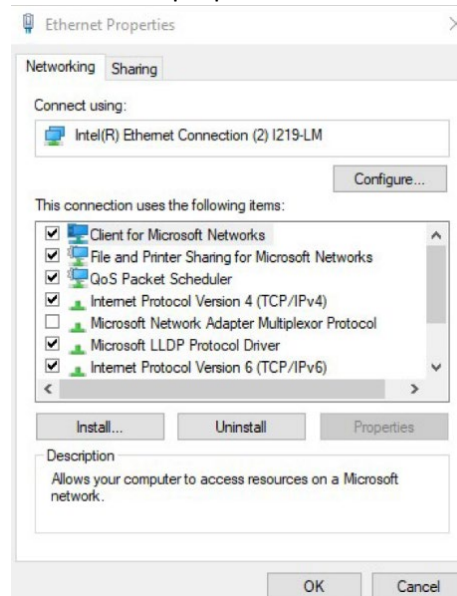


Figure 15: Windows Ethernet Properties

- 23 Select Internet Protocol Version 4 (TCP/IPv4) and then click on properties.
- 24 Change the settings to **obtain an IP address automatically** and **obtain DNS server address automatically**. Click ok to save changes. This will remove the plug and play functionality with the Ethernet cable to the ceilometer. This will also allow the PC to connect to networks using the onboard Ethernet port.
- 25 On the PC, open BL-View and navigate back to the settings menu previously configured in step 10. In the connection section, click the TCP Client radio button. The connection portion of the screen will repopulate as such:

The screenshot shows the 'BL-View - Settings' window with the 'Devices' tab selected. On the left, a list of devices includes 'CL51 Millbrook PAMS'. The main settings area is configured for a TCP Client connection. The 'File suffix' is 'PAMS_NCDEQ', and the 'File path' is 'C:\BLViewData'. Under the 'Connection' section, 'TCP Client' is selected. The 'Local port' is 1000, 'Device IP address' is 255.255.255.0, and 'Device port' is 4001. Under the 'Messages' section, the 'Message type' is 'msg1_10x1540' and the 'Message interval' is 36 seconds. At the bottom, there are 'Add', 'Delete', 'Save', 'Cancel', and 'Close' buttons. A license status at the bottom left indicates '1/1 Devices added'.

Figure 16: BL-View TCP Connections Setting

- 26 In the local port box enter 1000. This can be any port number desired.
- 27 In the device IP address box, enter the assigned static IP address of the MOXA device.
- 28 The device port will be one of the secure ports provided by Vaisala.
- 29 Change the Message type back to **msg1_10x1540** and set the message interval to 36 seconds. Click save and close. Data should begin to flow into the BL-View software over the network.

- 30 To finish the remote data configuration, open the MOXA Device Server by right clicking the MOXA Device Server icon and select properties. It will populate with the original IP address of the ceilometer, **192.168.127.254**. Change this address to the IP address of the MOXA device. Click ok to save.
- 31 Once configured and the communications are tested, the ceilometer can be powered down, disconnected, and packaged for transport to the Millbrook site in its original shipping container. The container is about 91 kilograms (200 pounds) and requires two people to lift.
- 32 Unpack the ceilometer and open the ceilometer housing. Slide out the ceilometer internal components and store inside the Millbrook shelter by loosening the set screws located at A in Figure 17. Take care to not touch the window or lens surface. Wear gloves while handling the equipment. Cover the laser window with a lint-free microfiber cloth while it is out of the instrument housing.

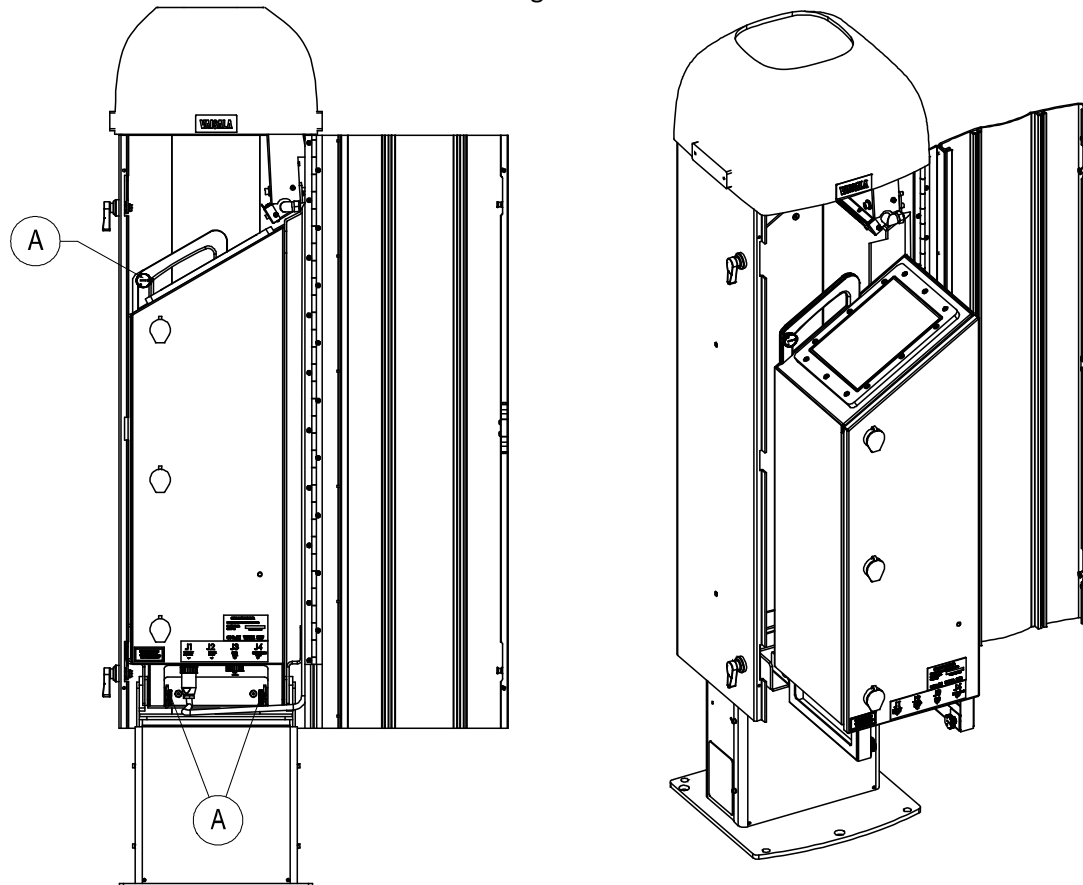


Figure 17: Vaisala CL-51 Ceilometer Instrument Internal Removal Diagram

- 33 Mount the ceilometer housing to the concrete pad using the 5/8 in anchor bolts. Clean any dust that accumulates on the ceilometer during the mounting process with a shop-vacuum. Reinstall the instrument internals, taking care not to touch the window or lens surface. Wear gloves while handling the equipment.
- 34 Plug in the ceilometer and open the ceilometer internals as done in step 6. Switch the main circuit breaker, heater blower breaker and battery backup switch to the on position. Close instrument internals and housing.
- 35 Connect to the ceilometer with the BL-view software on the PC. The ceilometer may take several minutes to boot and establish a connection.
- 36 Using a hammer, set the grounding rod behind the concrete pad and hammer it securely into the ground.
- 37 Cut a section of 10-gauge copper wire and strip about 1-2 inches of each end.

- 38 Slide 5/8 in grounding clasp onto the ground rod and secure the clasp and copper wire to grounding rod by tightening the ½ in nut with a driver.
- 39 Run the grounding wire along the ethernet conduit and secure it to the 4mm machine screw at the base of the ceilometer (depicted to the right of **A** in the bottom of figure 17) as shown below using a 10-gauge wire ring connector.



Figure 18: Vaisala CL-51 External Ground Depiction

- 40 Zip-tie the grounding wire into place along the conduit and at the top of the grounding rod.
- 41 Using a 125-foot fishing tape, feed the shielded ethernet cord through the conduit along the decking.
- 42 Run the cord through the underground conduit and into the monitoring shelters. Secure the cord using zip ties where necessary.
- 43 Connect the ethernet cord to the gigabit switch on the State WAN.

- 44 Launch BL-View on the connected computer and establish a connection. If trouble occurs, refer to section 9 of this document.

5.2 Ceilometer Operation

- 1 Connect to the ceilometer with the BL-view software on the PC.
- 2 The ceilometer has two modes of operation: normal and standby.
- 3 In **standby** mode components are powered off as active measurement is not occurring.
- 4 In **normal** mode, continuous measurement is instantaneously active and occur at the factory set parameters. The ceilometer should be run in normal mode unless maintenance needs to occur.
- 5 The site operator can remotely control the ceilometer with the BL-view software using Windows Remote Desktop. Alternatively, the site operator can perform any necessary functions while onsite. Data are transmitted from the ceilometer to the PC via a secure ethernet connection and is only collected while the PC and BL-View are both actively running.
- 6 The data are backed up monthly to the **P:** drive at the conclusion of each calendar month.

5.3 Ceilometer Data Transmission to the UCN and Data Reduction to obtain an MLH

In conjunct with the EPA, the UCN hosted by UMBC receives all the raw backscatter data from the Millbrook Site Vaisala CL-51 Ceilometer in real time via a secure FTP transfer. Full backscatter profiles are transmitted to UCN along with the triggered events file (.his files). The events file details any errors as well as routine functions of the ceilometer. E.g., the blower was triggered on at a particular time and subsequently shut off later. This allows UMBC to identify issues automatically and alert the agency of any issues that were not identified initially. The file transfer occurs every fifteen minutes beginning at the top of the hour. UMBC also has set up an alert system to automatically e-mail DAQ staff responsible for the ceilometer if it stops reporting data after multiple data transfer attempts. This is yet another failsafe to ensure the ceilometer remains operational.

UMBC will be responsible for determination of the MLH via their algorithm published in *Caicedo Et. Al.* in the *Journal of Atmospheric and Oceanic Technology* (2020). In short, the backscattered profile is analyzed using a custom written Matlab script to perform a covariance transform of the Haar wavelet function. Dilations of multiple Haar wavelets identify aerosol backscatter gradients and retrieve the MLH. These mathematical analyses can screen the data for quality, completeness, precipitation and stratified MLH. All data reduction methods are published and peer reviewed. Further information about the data reduction and analysis for PAMS ceilometry is available in the publication aforementioned and referenced in latter sections.

6.0 DATA REVIEW

This section of the SOP describes steps required for the primary Laboratory Analysis Branch (LAB) to perform a self/Level 1 review on the ceilometer data. Additionally, this section describes steps required for UMBC to perform a peer/Level 2 data review and independent level 3 ceilometer data review and validation.

6.1 Self/Level 1 Ceilometer Data Review

The BL-View software reports data quality index with BL/mixing height measurements. These indices range from 1 to 3: 1 indicates poor quality, 2 indicates marginal quality and 3 indicates good quality. Vaisala recommends that data with a quality index of 2 or greater be considered valid. Data quality with an index of 1 should not be considered valid without further review. The operator can inspect the back scatter profile graphically in BL-view

and examine the suitability of assigned hourly MLH to verify whether data with poor quality indices are valid. Note that for hours where there is substantial precipitation and/or fog, there may not be a reportable MLH. Hourly MLH data will be reported to EPA through the UCN.

At the time of publication of this document, reporting of hourly MLH to the air quality system (AQS) is under development and EPA intends to communicate with monitoring agencies regarding future establishment of data verification and data validation routines. UMBC will serve as the data reviewers and validators for collected ceilometer data performing level 2 and 3 review. DAQ has developed a quick checklist to review the collected backscatter data. It is available for inspection in Appendix C. The data review checklist is an efficient way for DAQ to further document any potential issues with the ceilometer as well as compare and contrast the meteorological results to look for a diurnal pattern.

The PAMS Vaisala CL-51 Ceilometer at the Millbrook site operates with a laser at 910 nm pulsed into the atmosphere above the site. The emitted radiation interacts with aerosols above the site and results in scattering of the laser pulse. The backscattered radiation is measured by the ceilometer and becomes the data set to determine MLH. Figure 19 depicts a typical diurnal pattern observed on a clear day:

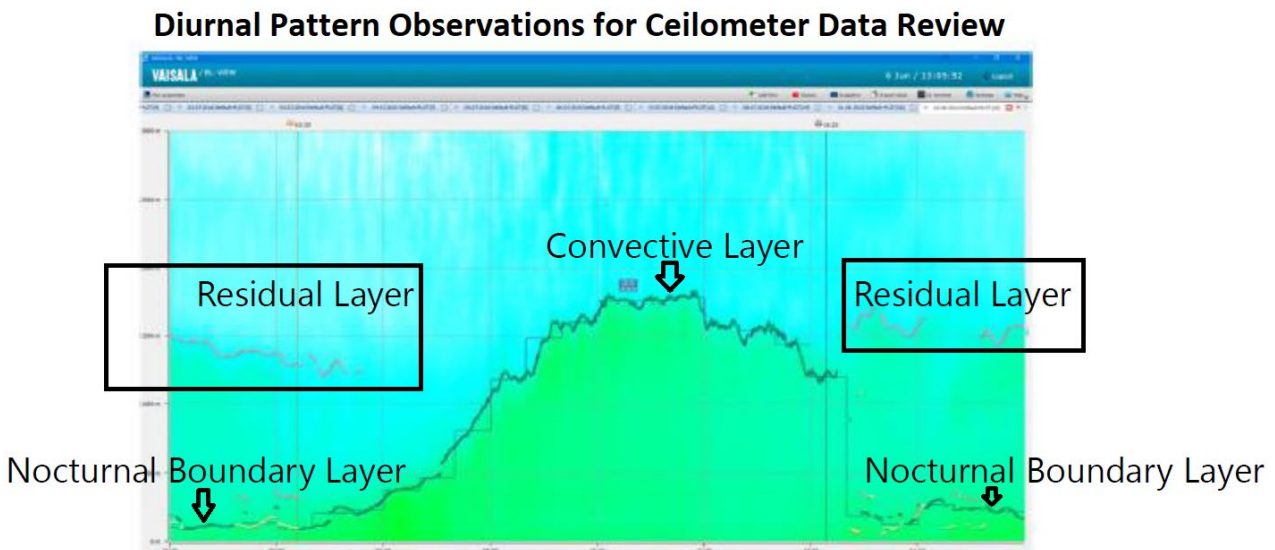


Figure 19: Diurnal Pattern Observations for Ceilometer Data on a Cloudless Day

On a cloudless day as the sun comes out, convection in the atmosphere increases and causes the MLH to elevate throughout the day as a function of solar radiation. This will crest around mid-day and gradually decrease as the sun sets. This observed layer, between sunset and sunrise is appropriately named the **convective layer**. After the sun completely sets, radiational cooling of the atmosphere occurs and causes rapid sinking of the mixing layer. This layer occurs near ground level and is called the **nocturnal boundary layer**. A **residual layer** is often observed as not all the aerosols above the ceilometer sink equally. The **residual layer** will be observed above the **nocturnal boundary layer**.

Days with observed inclement weather are known to interfere with MLH determinations. During days with clouds producing rainfall, data should be compared against the Met One precipitation rain gauge, ultra-violet radiation, solar radiation, ambient temperature, and wind speed for the Millbrook Site using Envista ARM on an hourly time base. Days with precipitation will scatter radiation with a high intensity and look akin to what is shown **above in Figure 20**.

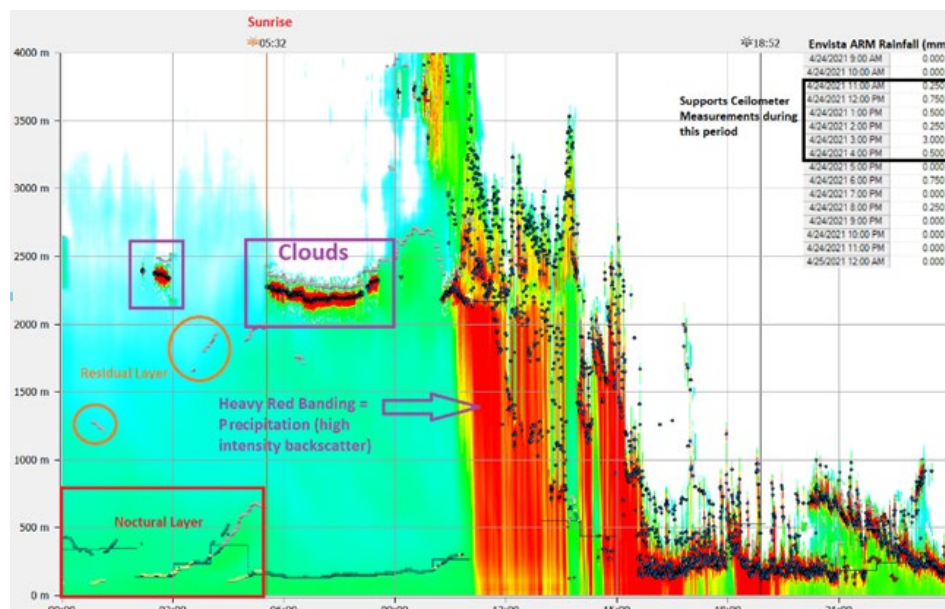


Figure 20: Clouds and Rainfall in Ceilometer Data

Days with ground level clouds, i.e., fog, produce high intensity backscatter near the ground level and look akin to the ceilometer data below in Figure 21:

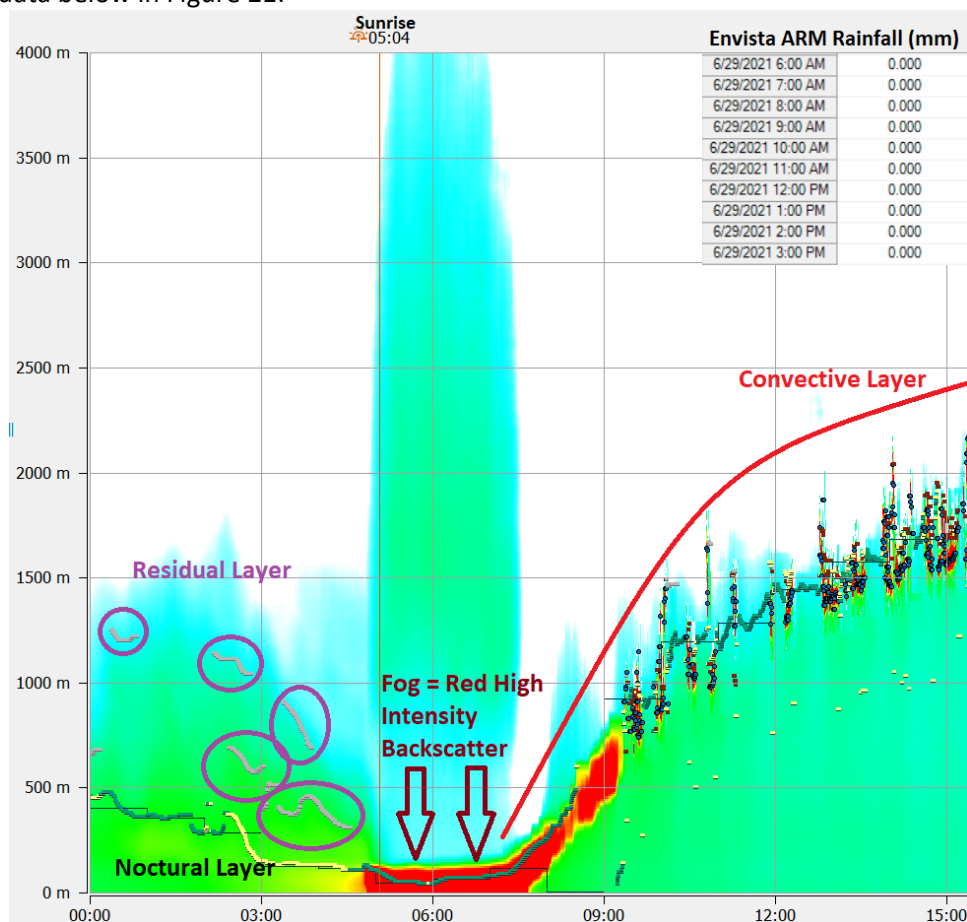


Figure 21: Ceilometer Data, Fog and Day Time Convection

Note that the Envista ARM precipitation data supports no measured rainfall at the site in figure 21, indicating that the high-intensity backscatter observed is not a result of precipitation.

Environmental factors to consider in the review of ceilometer data include:

- Local source influence – Any nonroutine event that would generate aerosols.
 - Fire/smoke
 - Construction activities
- Low aerosol concentrations – Produces low backscatter profiles

Other metrological factors to consider in the general review of ceilometer data include:

- Solar Radiation and Ambient Temperature are directly correlated
 - Solar Radiation – Allows convection to occur
 - Ambient Temperature – Rises in ambient temperature will cause the MLH to rise due to increased convection. Rapid temperature increases can impact hourly reported averages.
- Moderate-to-high winds – Disperses aerosols
 - Refer to the Beaufort Wind Scale below in **Table 1**:

Table 1: Beaufort Wind Scale₁					
Beaufort Wind Scale	WMO Classification	Wind Speed (Knots)	Wind Speed (mph)*	Wind Speed (m/s)*	Appearance of Wind Effects On Land
0	Calm	Less than 1	Less than 1.15	Less than 0.51	Calm, smoke rises vertically
1	Light Air	1-3	1.15-3.45	0.51-1.54	Smoke drift indicates wind direction, still wind vanes
2	Light Breeze	4-6	4.60-6.90	2.06-3.09	Wind felt on face, leaves rustle, vanes begin to move
3	Gentle Breeze	7-10	8.06-11.50	3.60-5.14	Leaves and small twigs constantly moving, light flags extended
4	Moderate Breeze	11-16	12.66-18.41	5.66-8.23	Dust, leaves, and loose paper lifted; small tree branches move
5	Fresh Breeze	17-21	19.56-24.17	8.74-10.80	Small trees in leaf begin to sway
6	Strong Breeze	22-27	25.32-31.07	11.32-13.89	Larger tree branches moving, whistling in wires
7	Near Gale	28-33	32.22-37.98	14.40-16.98	Whole trees moving, resistance felt walking against wind

Table 1: Beaufort Wind Scale ₁					
Beaufort Wind Scale	WMO Classification	Wind Speed (Knots)	Wind Speed (mph)*	Wind Speed (m/s)*	Appearance of Wind Effects On Land
8	Gale	34-40	39.13- 46.03	17.49- 20.58	Twigs breaking off trees, generally impedes progress
9	Strong Gale	41-47	47.18- 54.09	21.09- 24.18	Slight structural damage occurs, slate blows off roofs
10	Storm	48-55	55.24- 63.29	24.69- 28.29	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	Violent Storm or Tropical Storm	56-63	64.44- 72.50	28.81- 32.41	
12	Hurricane	64+	73.65+	32.92+	
*Values in between scale ratings should be placed into the previous bracket due to unit conversions and rounding.					
₁ https://www.spc.noaa.gov/faq/tornado/beaufort.html					

Moderate-to-high wind speeds are defined by the National Weather Service² as sustained winds above 26 mph or frequent gusts of 35 to 37 mph. This registers as a 6 or higher on the Beaufort Wind Scale.

Chiefly among data review considerations is: Do the observed changes in MLH make physical sense against the observed metrological conditions? To record these observations, a ceilometer data review checklist has been developed as shown in Appendix C. It will be completed for each day's data to examine the diurnal pattern and look for data impacts from the environment. The completed checklist is stored on the **P-drive**.

² https://www.weather.gov/mlb/seasonal_wind_threat

6.2 Peer/Level 2 Ceilometer Data Review

The UMBC atmospheric LIDAR group will analyze uploaded data segments with their published algorithm (*Caicedo Et. Al.*) and store it in a unified database: the UCN. All data are processed with custom written scripts and the outputted data are available at <https://www.ucn-portal.org/> for any participating ceilometer in the program. The Millbrook site will be displayed under Raleigh, NC. At the time of publication of this document, reporting of hourly MLH to AQS is under development and EPA intends to communicate with monitoring agencies regarding future establishment of data verification and data validation routines. UMBC-UCN will serve as the data reviewers and validators for collected ceilometer data preforming level 2 and 3 review.

6.3 Level 3 Ceilometer Data Validation

The UMBC atmospheric LIDAR group will analyze uploaded data segments with their published algorithm (*Caicedo Et. Al.*) and store it in a unified database: the UCN. All data are processed with custom written scripts and the outputted data are available at <https://www.ucn-portal.org/> for any participating ceilometer in the program. The Millbrook site will be displayed under Raleigh, NC. At the time of publication of this document, reporting of hourly MLH to AQS is under development and EPA intends to communicate with monitoring agencies regarding future

establishment of data verification and data validation routines. UMBC-UCN will serve as the data reviewers and validators for collected ceilometer data performing level 2 and 3 review.

7.0 CEILOMETER FILE MANAGEMENT

This section of the SOP describes the different files generated during the active measurement mode of the ceilometer and the individual required to manage the file, either the ceilometer operator or the UCN. Files include any ceilometer data files from active measurement.

7.1 Ceilometer Data Files (Site Operator)

The ceilometer generates data continuously and securely transmits the data to a PC computer on the State of NC network. The BL-View archives the raw signal data files in three file types: image, network common data form (netCDF), and American Standard Code for Information Interchange (ASCII) text files.

Image files capture the raw laser pulse data as a height versus time plot. Image files include timestamped received signal intensity information from each laser pulse and are archived to evaluate offline.

The BL/MLH measurements produced by BL-view are recorded simultaneously in both the netCDF and ASCII text files. ASCII text files also have been processed through an automated quality control process and evaluated with a data quality index as described in section 6.1. The ASCII text files are saved as .his files in the BL-view directory.

7.2 UCN Data Files (UCN Servers)

The ceilometer generates data continuously and securely transmits the data to the UCN. The UCN receives the ASCII .his files for the backscatter and event files. At the end of each day an FTP receipt is generated to indicate successful transfer of the data files has occurred. The UCN employs its own data redundancy protocols which safeguard data in case of computer failure. Data are available for download through the UCN website at <https://www.ucn-portal.org/>

7.3 Ceilometer Data Review Checklist (Site Operator)

The ceilometer data review checklist will be completed for each day and any observations recorded. The completed checklist will be stored in the **P-Drive** for reference, as needed.

8.0 FILE QUALITY ASSURANCE

8.1 Records Management

The site operator logbook will document installation, maintenance, or removal/replacement of any component of the ceilometer system. Any instrument outages must also be recorded.

8.2 Monthly Backup of Ceilometer Data

At the conclusion of each calendar month all generated data must be copied to the external backup hard drive or server environment for archival.

9.0 TROUBLESHOOTING AND CORRECTIVE ACTIONS

General steps and troubleshooting actions to take when the ceilometer is not functioning appropriately.

9.1 Ceilometer Warning or Alarm Message

- 1 Refer to the table in Appendix B for the code, reason and corrective action for any particular error message. This table is from the operator's manual and was generated by the manufacturer.
- 2 To view active alerts, select the alerts menu and the BL-view software will display the active errors. A symbolic code is used to aid the site operator in rapidly identifying errors with the figure below:




Icon	Description
	No alerts
	1 or more warnings Measurement data is valid
	1 or more alarms, and possibly also warnings Measurement data may be invalid

Figure 22: Vaisala BL-View Symbolic Alert Key

- 3 The BL-view software will communicate software operational status, ceilometer hardware status, ceilometer communications status and system errors.

9.2 Dirty Ceilometer Window Corrective Action

- 1 If the window is observed to be dirty, or the CL51 has issued a **window contaminated** warning, get clean water, lint-free microfiber clothes and a mild detergent to clean the window.
- 2 Open the ceilometer housing and verify blower operation. Unless already running, the blower should start when you block the laser beam with your hand or cover the laser window with the cleaning cloth, for about 15 seconds or more. If the blower does not trigger, see section 9.5.
- 3 Keep the instrument internals door closed and gently flush the window with clean water to remove any coarse grains that could scratch the surface.
- 4 Clean the window with the lint-free microfiber cloth and mild detergent. Again, be mindful of the pressure applied to the window and take care to not scratch the surface.
- 5 Dry the window with another lint-free microfiber cloth, ensuring no stains or solid particles remain on the window.

9.3 Dirty Door Gasket Corrective Action

- 1 If the door gasket is observed to be dirty during inspection, wipe with a lint-free microfiber cloth.
- 2 Water and a mild detergent can be used to clean the gasket, if needed.
- 3 Wipe dry with a clean, microfiber cloth and close the unit.

9.4 Battery Damage Corrective Action

- 1 If battery damage is observed during inspection, disconnect the positive (+) and negative (-) terminals and switch the battery to the off position.

- 2 Power down the ceilometer by placing all switches in the off position and record the outage and maintenance in the electronic logbook.
- 3 Remove the battery by opening the battery cage lid with the two lock screws with a 3 mm hex key.
- 4 Open the cage lid and slide out the battery. Be sure to wear gloves if there is any leakage of electrolyte.
- 5 Clean any dirty spots inside the ceilometer with water, a mild detergent and a lint-free microfiber cloth. Dab with a damp microfiber cloth; do not apply liquids inside the ceilometer housing. Dry with a new dry lint-free microfiber cloth.
- 6 Reinstall a new battery by sliding it in the cage, closing the cage and reinstalling the two locking screws.
- 7 Reinstall the positive (+) and negative (-) battery cable to the positive (+) and negative (-) terminals and switch on the battery and other power throws.
- 8 Wait for the ceilometer to boot and establish a connection to BL-view to verify replacement was successful. This may take several minutes.

9.5 Blower Failure Corrective Action

- 1 If the blower does not operate particulates can build up on the instrument window and decrease ceilometer performance. If a blower error occurs, confirm that the blower is connected, and the power switch is on.
- 2 If all electrical connections are okay, the blower may be stuck or damaged. Open the ceilometer and visually inspect the blower for reasons why it would not function.
- 3 Reset the blower by rebooting the ceilometer.
- 4 If the automated blower test fails within the first 5 minutes of boot up, then the blower likely requires replacement. Contact Vaisala support at helpdesk@vaisala.com for further guidance on replacing the blower.

9.6 Instrument PC Time Incorrect

- 1 The instrument PC time is set by the NC Department of Information Technology (DIT) and cannot be adjusted without an administrator. File a ticket with DIT immediately if this is incorrect.
Note: DAQ does not observe or correct for daylight savings time when setting monitoring equipment PC times.

9.7 Ceilometer Troubleshooting via Maintenance Connection

Note: This procedure will stop data collection if the maintenance connection is established.

- 1 Connect the QMZ101 maintenance cable to port 4 of the ceilometer and to the RS-232 port of the PC.
- 2 Open the terminal program putty with the following settings: bit rate 9600, data bits 8, stop bits 1, parity none, handshake none and connect to the ceilometer.
- 3 Open the CL51 maintenance with the open command. The prompt CEILO> will appear.

- 4 Enter command GET FAILURE STATUS and press enter. An example output is shown in Figure 23:

```

Alarms
  Tmit Shutoff    OK      Transmitter    ALRM
  Receiver        OK      Voltages       OK
  Ext Memory      OK      Light Pth Obs  OK
  Rec Saturat     OK      Coaxial Cable  OK
  Engine          OK

Warnings
  Window Contam   OK      Battery Low    OK
  Transm Expire   OK      Humid High     OK
  Blower          OK      Humid Sensor   OK
  Int Heater      OK      High Rad       OK
  Engine          OK      Battery        OK
  Laser Monitor   OK      Receiver       OK
  Tilt Angle      OK

System Status:    FAIL
Suspect Module:   CLT

```

Figure 23: Vaisala CL-51 Ceilometer Maintenance Terminal Failure Status Check

The last two lines in the status message will indicate if there are warnings or alarms present. The suspect module line indicates the component that is suspected to be faulty. Notice the ALRM status for the transmitter and the corresponding system status message.

- 5 Contact Vaisala support at helpdesk@vaisala.com for further guidance based on the status message.

9.8 Data Does Not Flow into BL-View Corrective Actions

- 1 If data does not flow into BL-View from the ceilometer, then confirm that all ethernet cables are connected at both terminals.
- 2 Open google chrome and enter the static IP address of the MOXA box. If unknown, it will be labeled on the internals of the ceilometer along with the moxa box password. If the system does not find the designated IP address, contact DIT and Vaisala for further assistance. The ceilometer IP address has been changed.
- 3 Have DIT assign a new static IP address by providing the desired IP address and media access address (MAC) of the MOXA unit to DIT. Each time the unit comes online the router should reserve the designated IP address for the MOXA unit using the MAC address.
- 4 If the above steps do not yield a solution, have DIT port forwarded three secure ports for Transmission Control Protocol (TCP) data transmission. The ports required are the port number entered in section 5.1, step 17-18 and 26 and are typically 4001, 4002 and 1000.
- 5 If the issue persists work with DIT and Vaisala to find a solution. Vaisala can be contacted at helpdesk@vaisala.com.

10.0 REVISION HISTORY

1. 10/01/2021 **BDV** – Initial Draft (R0)
2. 03/01/2021 **BDV** – Conversion to SOP for SOPs format (R1)
3. 11/08/2021 **BDV** – Periodic Update for R2:
 - a. Updates to materials and equipment as needed
 - b. Updates to figures as needed
 - c. Added references and applicable details to the UCN as needed
 - d. Added semi-annual checks for instrument performance
 - e. Updated message type to msg1x1540; sky condition disabled to reflect operating parameters

- f. Changed references about a cellular modem to state WAN.
- g. Added data review information and checklist
- h. Updated format of SOP to follow updated DAQ SOP format
- i. Added troubleshooting section
- j. Updated section 5.1 to include grounding rod and ethernet installation.

11.0 REFERENCES

1. Vaisala (2010) CL-51 Ceilometer: User's Guide. Helsinki, Finland. Vaisala oyj.
2. Vaisala (2019) CL-31 & CL-51 Ceilometer: Plug & Plug Initial Setup and Network Modification. Louisville, CO. Nicoll, Tim.
3. North Carolina Department of Environmental Quality, Division of Air Quality (2021). Quality Assurance Project Plan for the North Carolina Division of Air Photochemical Assessment Monitoring Stations (PAMS) Required Site Network for Speciated Volatile Organic Compounds, Carbonyls, and Meteorological Parameters Including Mixing Layer Height. Revision 0. Raleigh, NC. DAQ Document ID: DAQ-01-007. Steger, Joette; Walters, Steven and Velleco, Brian D.
4. Vanessa Caicedo, Ruben Delgado, Ricardo Sakai, Travis Knepp, David Williams, Kevin Cavender, Barry Lefer, and James Szykman (2020). An Automated Common Algorithm for Planetary Boundary Layer Retrievals Using Aerosol Lidars in Support of the U.S. EPA Photochemical Assessment Monitoring Stations Program. *Journal of Atmospheric and Oceanic Technology*: Volume 37, Issue 10 Pgs. 1847-1864. American Meteorological Society: Boston, MA.

12.0 APPENDICES

1. Appendix A – EPA Technical Note for Participation in the UCN
2. Appendix B – CL-51 Warning and Alarm Messages
3. Appendix C – Ceilometer Data Review Checklist

Appendix A – EPA Technical Note for Participation in the UCN



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY RESEARCH TRIANGLE PARK, NC 27711 OFFICE OF AIR QUALITY PLANNING AND STANDARDS

Technical Note - Participation in the Unified Ceilometer Network August 30, 2021

The purpose of this technical note is to introduce the Unified Ceilometer Network (UCN) and to inform monitoring agencies that participation in the UCN will satisfy the requirement to measure and report hourly averaged mixing layer height at PAMS sites as required under 40 CFR part 58.

BACKGROUND

The PAMS monitoring requirements promulgated in 2015 call for monitoring agencies to measure and report hourly averaged mixing height at PAMS sites. Most agencies are using ceilometers to make the mixing height measurement due to their low cost and ease of operation.

Since the promulgation of the PAMS requirements, EPA has noted the value of the full backscatter vertical profile measured by ceilometers. The backscatter data from ceilometers can not only be useful in estimating mixing height but can also be used for other air quality purposes such as air quality forecasting and the evaluation of smoke impacts from wildfires. Furthermore, the backscatter profiles allow for better visualization of atmospheric mixing processes valuable to air quality evaluations.

INTRODUCING THE UNIFIED CEILOMETER NETWORK

Due to the value of the full backscatter profile, EPA in conjunction with the University of Maryland, Baltimore County (UMBC) and NASA, developed a new data system for the collection, storage, and retrieval of ceilometer data called the Unified Ceilometer Network (UCN).

The UCN is an open network designed to automatically retrieve and store ceilometer profile backscatter from participating ceilometers. A number of options are available for data collection based on the IT requirements of the partner monitoring agency.

One major advantage of the UCN is that it allows consistency in the mixing layer height retrievals. The UCN provides centralized processing of aerosol backscatter profiles through the use of a common (peer-reviewed) algorithm to derive aerosol layers heights with a classification scheme to identify mixing heights, nocturnal stable layers, and residual layers. The UCN also includes internal quality assurance checks with explicit treatment of clouds and precipitation to minimize incorrect identification of aerosol layer heights and associated mixing heights. Because of the central data processing, common application of an algorithm, and QA checks, the UCN system alleviates much of the burden on monitoring agencies regarding the derivation of hourly mixing layer heights by a ceilometer. Finally, by storing the full aerosol backscatter

profile data, improvements to the algorithm can be applied to archived data and reflect the most recent mixing layer height algorithms.

In addition to archived backscatter data, the UCN provides near-real time display of current backscatter conditions. Air quality forecasters will be able to use the backscatter data from the multiple sites in the UCN to improve air quality forecasts, and all air quality agencies will have data access for other uses such as model evaluation and exceptional event analysis.

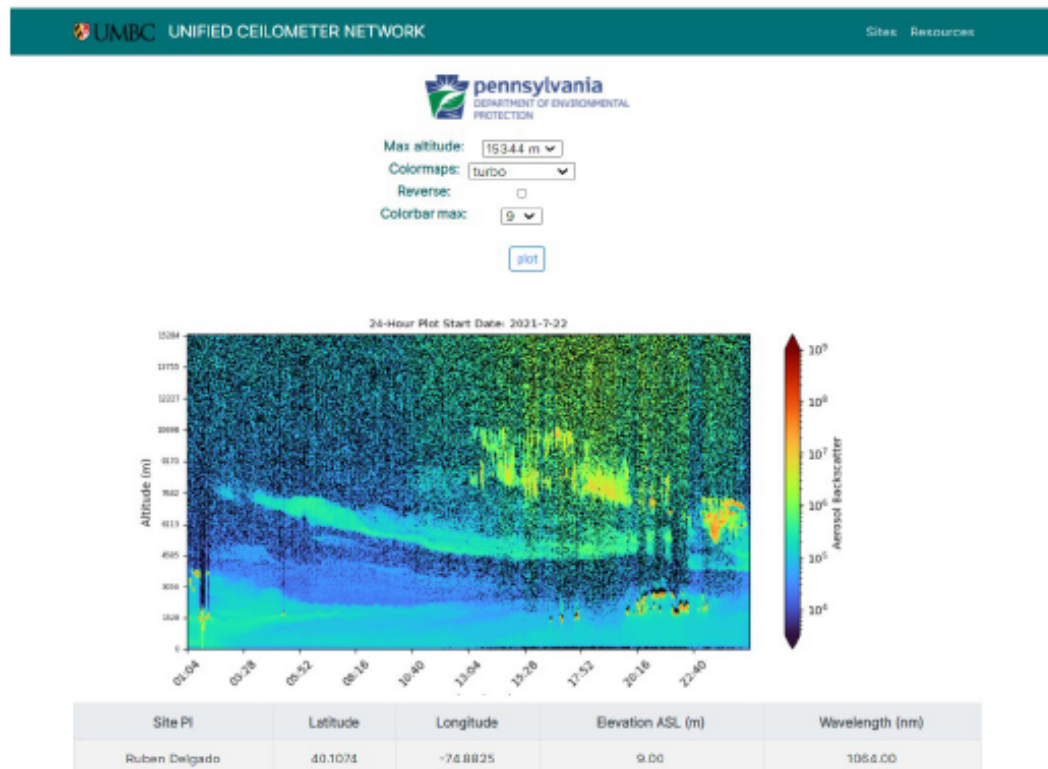


Figure 1. Near-real time visualization webpage for UCN. Visualization page will include a default rolling 24-hour image, and options for visualization in various altitude ranges, colorscales, and time range.

PARTICIPATION IN UCN

The UCN is open to any monitoring agency wishing to participate. Note that participation in UCN is voluntary and monitoring agencies may instead choose to meet the PAMS requirement for reporting hourly mixing layer height by directly reporting their derived mixing height to AQS. However, due to the advantages provided by collection of the full backscatter profile, EPA will consider participation in the UCN as satisfying the requirement to report hourly mixing layer height at PAMS sites.

Monitoring agencies should contact Kevin Cavender (cavender.kevin@epa.gov) for more information on the UCN including information on how to participate.

Appendix B – CL-51 Warning and Alarm Messages

Status Message Info	Reason	Instructions
Window contamination warning (appears from time to time and lasts < 5 min).	Usually drizzle drops on the window.	The blower will clean the window. If clouds are detected, the height information is correct. If no clouds are detected, it is possible that high clouds are missed.
Window contamination warning (continuous).	Bird droppings, leaves, dust etc. have contaminated the window.	Clean the window.
Battery low warning	The unit has been powered too long using the backup battery.	Connect the line voltage or replace the battery.
	Recharging of the battery has failed.	If the battery is old, replace it. If the battery is OK, check the operation of Ceilometer Engine Board CLE321.
Transmitter expires warning.	Laser diode is too old.	Replace Transmitter CLT521. The measurement data is valid, but it is possible that some clouds are missed.
High humidity warning (option)	Relative humidity > 85 %. Water has been condensed inside the ceilometer. Leakage in the enclosure or leakage in the door.	Take the ceilometer inside, open the maintenance door and let it dry in a warm air conditioned place. Condensed water on optical surface may disturb the measurement. There is a danger of short circuits.
Blower failure warning.	Blower cable is not connected.	Check that the blower cable is connected.
	Window blower circuit breaker is not ON.	Check that the window blower circuit breaker is ON.
	Line voltage level is not correct.	Check that the line voltage is present and correct.
	Blower is stuck.	Check if visible obstacles disable blower operation.
	Blower is damaged.	Replace the blower.
Humidity sensor failure warning (option)	Humidity sensor is not connected.	Connect the humidity sensor or disable the option in the software.
	Humidity sensor is damaged.	Replace the humidity sensor.
Heater fault warning	Window blower circuit breaker is not ON.	Check that the window blower circuit breaker is ON.
	Line voltage level is not correct.	Check that the line voltage is present and correct.
	Heater is damaged.	Replace the heater.
High background radiance warning	Ceilometer is pointing directly to the Sun.	In case there are no alarms, the measurements are OK. If there is an alarm, the measurements are invalid.
Ceilometer Engine Board failure warning	Non-critical fault in Ceilometer Engine Board CLE321.	Replace Ceilometer Engine Board CLE321.
Battery failure warning	Battery is dead.	Replace the battery.

Status Message Info	Reason	Instructions
Laser monitor failure warning	Laser power monitor board CLM311 has failed.	Replace CLM311.
	Laser power measurement on Ceilometer Engine board CLE321 has failed.	Replace CLE321.
Receiver warning	A non-critical CLR321 Receiver failure.	Replace CLR321.
Tilt angle > 45° warning	The unit is not correctly installed or the tilt angle is larger than 45°.	Check the installation. The height measurement accuracy is lost with tilt angles greater than 45°.

Table 23 CL51 Status, Alarms

Problem	Reason	Instructions
Transmitter shut-off alarm (Laser temperature > 85°C)	Direct sunlight has heated the laser.	Wait for the Sun to exit the field-of-view. CL51 will return to normal operation.
	Environment temperature too high.	Check if there is a specific reason for the high temperature.
Transmitter failure alarm	Laser is worn out or damaged.	Replace Laser Transmitter CLT521.
	Laser does not get electrical power.	Check from the status message that the line Voltages is marked OK.
Receiver failure alarm	Receiver CLR321 is damaged.	Replace CLR321.
	Loose cable connection.	Check that the cables from Receiver CLR321 and Ceilometer Optics Unit CLO511 are undamaged and correctly connected.
	Receiver test not operating.	Check that the Optics Unit CLO511 is not misplaced or damaged.
Voltage failure alarm	Ceilometer Engine Board CLE321 is damaged.	Replace CLE321.
Memory error alarm	A failure in the CLE321 memory.	Replace CLE321.
Light path obstruction alarm	Window is badly contaminated or severely scratched.	Clean the window or in case of damage, replace CLW511.
	Something blocks the laser beam.	Check the clarity of the optical path.
Receiver saturation alarm	Ceilometer is pointing directly to the Sun.	Wait for the Sun to exit the field-of-view. CL51 will return to normal operation.
	Something is partially blocking the laser beam.	Check the clarity of the optical path.

Appendix C – Ceilometer Data Review Checklist

SOP DAQ-07-001.2 PAMS Ceilometer Data Review Checklist

Date: _____			
Primary Reviewer (Initials/Date): _____			
Level 2 Peer Reviewer and Level 3 Validator: University of Baltimore Maryland County (UMBC)			
Daily Data Review	Level 1 Primary Review (Check One)		Comments
Data Completeness:	Yes	No	
Is data complete for the 24-hour period? If data is missing notate as to why and refer to relevant logbook entries.			
FTP Receipt Present?			
Diurnal Pattern - Is the following observed?	Yes	No	
Nocturnal Layer (Morning, Pre-Sunrise):			
Residual Layer (Morning, Pre-Sunrise):			
Convective Layer (Between Sunrise and Sunset):			
Nocturnal Layer (Evening, Post-Sunset):			
Residual Layer (Evening, Post-Sunset):			
Metrological Conditions:	Yes	No	
Precipitation?			
Fog?			
Moderate-to-High Winds (26+ mph or 11.63m/s)?			Max hourly average -
Environmental Conditions:	Yes	No	
Any exceptional events to note? e.g., fire/smoke, construction.			