Ceilometer Standard Operating Procedure

By

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For the

Air Quality Program

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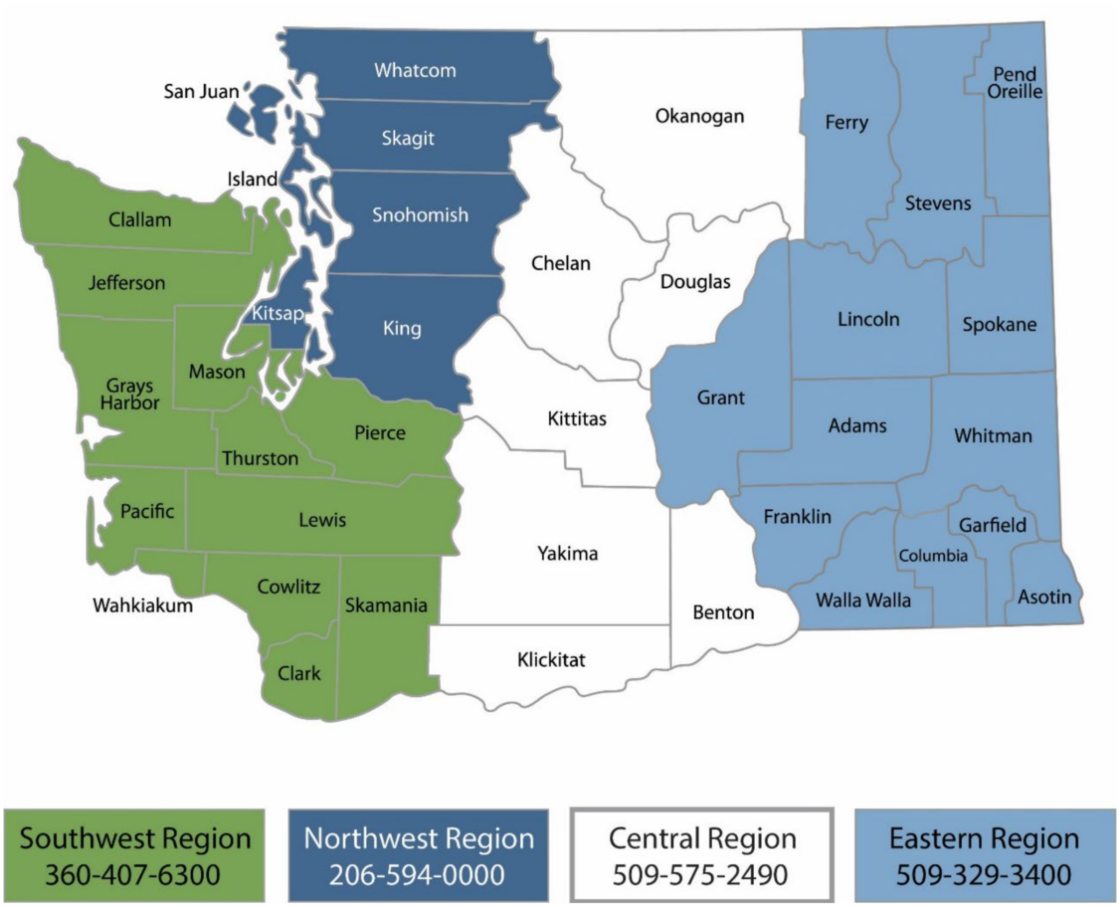

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Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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ECOLOGY
State of Washington

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1. Introduction

This standard operating procedure describes the requirements and guidance for operating Vaisala CL51 Ceilometers (Figure 1) for Measuring Mixing Height within the Washington State Ambient Air Monitoring Network (Washington network). The Mixing Height Layer (MHL) is the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence. One hour Mixing Height Layer is a required parameter for the U.S. Environmental Protection Agency (EPA) Photochemical Assessment Monitoring Stations (PAMS) Required Site network. Currently there is only one ceilometer operating in Washington State's network, at the PAMS site at Seattle Beacon Hill. This document is intended to summarize the Vaisala Ceilometer CL51 User's Guide.

It is recommended that the user's guide be used in conjunction with this document during installation and operation of the instrument.

Figure 1: Vaisala CL51 Ceilometer

2. Health & Safety Warnings

The CL51 has been tested for safety and approved prior to shipment from the factory. Safety precautions must be observed during all phases of setup, commissioning, operation, service, and repair. Users must not modify the unit as improper modification can damage the instrument and may lead to a malfunction. Questions should be directed to the Vaisala product support department.

The CL51 is classified as a Class 1M laser device in accordance with international standard IEC/EN 60 825-1. The CL51 complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to the Laser Notice No. 50 dated 26 July 2001. When the CL51 is installed in a field environment, configured with instrument covers, and pointed vertically or near-vertically, it poses no established biological hazard to humans.

The CL51 is delivered with the following label:

The CL51 is intended for operation in an area restricted from public access. It is to be pointed vertically or at a shallow zenith angle. Invisible laser radiation is emitted through the aperture, depicted in Figure 2, on the top of the ceilometer.

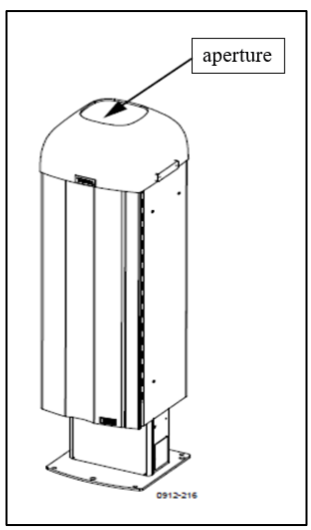

Figure 2: Ceilometer CL51 Laser Aperture

Do not look directly into the ceilometer transmitter (aperture) or ceilometer optics with magnifying optics (e.g., glasses, binoculars, or telescopes). Never remove the ceilometer transmitter from its normal position without first switching off the AC power line voltage, switching off the battery power, and detaching the transmitter ribbon cable from the ceilometer engine board. When operating the CL51, avoid looking at the ceilometer unit from the beam direction or aperture. If the unit is tilted, ensure that it is not being viewed from the beam direction with magnifying optics.

Finally, as a precaution, only trained personnel should perform maintenance functions. Access to the work area by unauthorized persons during service operations must be prevented.

3. Principles of Operation

The Vaisala Ceilometer CL51 measures cloud height and atmospheric visibility as part of its internal processing. The addition of the laptop computer executing the BL-View software package enables the detection of up to three (3) independent local BL heights per profile. The lowest of these BL heights is typically considered the mixed layer or mixing layer.

The CL51 utilizes pulsed diode laser technology (LIDAR = Light Detection and Ranging), where short, powerful laser pulses are emitted into a vertical or near-vertical direction. The reflection or backscatter of the LIDAR pulse is the consequence of the interaction of the light signal with local atmospheric-borne particulates such as air pollution, haze, fog, mist, virga, precipitation, and clouds. The backscatter profile, that is, the signal strength versus sample time (related to the altitude), is stored and processed, after which it is used by BL-View to determine the local BLs/mixing height(s). The time interval between the emission of the laser pulse and the reception of the backscatter signal is directly related to the altitude from which the signal is reflected.

The CL51, with the BL-View software package, is able to identify the cloud layers and the BLs/mixing heights simultaneously. The CL51 firmware supports several service and maintenance functions.

3.1. Basic operating principle

The CL51 employs a pulsed InGaAs (Indium Gallium Arsenic) diode laser operating at a wavelength of 910 nm. The CL51 functions as a monostatic and monochromatic, pulsed LIDAR source by emitting a pulse of light and then recording and processing the received signal produced by the interaction of the light energy with the particles carried by the atmosphere. At any given altitude, the measured signal intensity is proportional to the number of particles at that altitude.

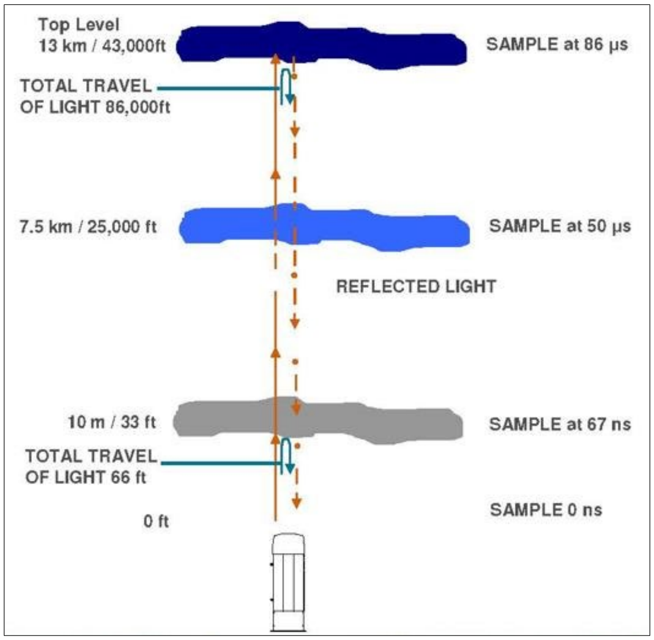

Figure 3: The CL51 LIDAR sampling process detailing the transmission and reflection of a laser pulse

When in operation, a 100-nanosecond (ns) pulse (equivalent to a 15-meter depth) is emitted every 150 microseconds (s). The ceilometer measures profiles 6500 times per minute and uses 32,768 of these profiles for each measurement cycle. A schematic diagram of the LIDAR measurement process is shown in the Figure 3.

The time history (corresponding to sampling heights) of the signal intensity is recorded by the instrument. BL-View uses this to identify the BL heights, one of which correlates to the local mixed layer at any given point in time.

3.2. BL-View

Vaisala Boundary Layer View BL-View is a software application for planetary boundary layer analysis and visualization. The software records the pulse profiles through the network connection and then uses this information to compute the MLH estimate(s). The BL-View software can detect up to three (3) BLs/MLHs simultaneously. Coupled with the embedded CL51 cloud detection algorithm, the software also reports up to three (3) cloud heights. However, as cloud heights are outside the scope of the PAMS network, the cloud detection techniques and applications will not be discussed further in this document.

The CL51 signal profile detection is based on the profile of the size and number of the particles distributed vertically in the atmosphere above the unit. A sample of this signal profile is shown below in Figure 4.

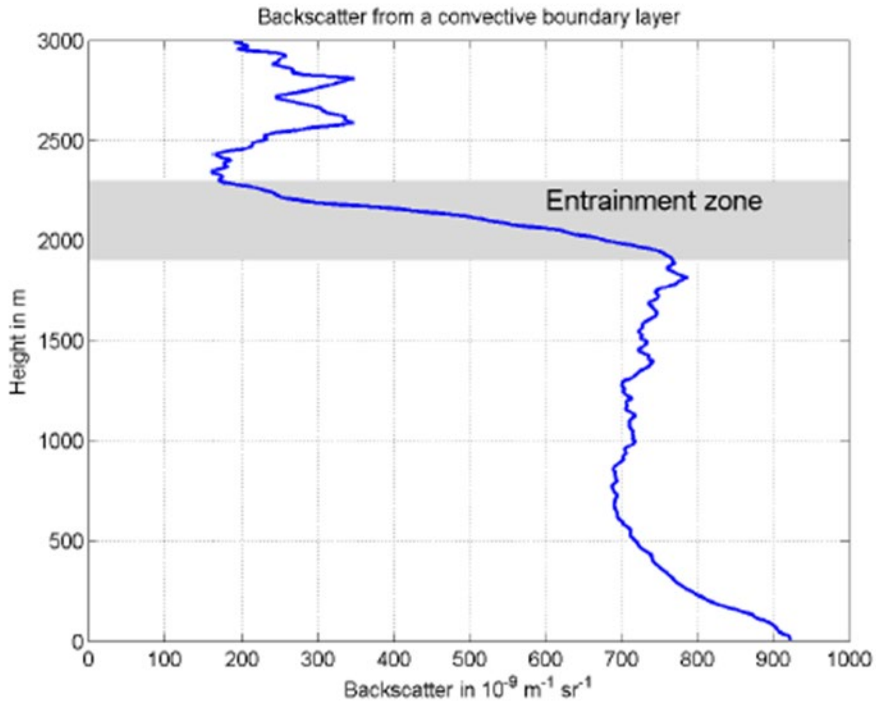

Figure 4: Backscatter signal intensity profile demonstrating the entrainment zone

This profile shows the well mixed layer (region beginning at the ground (altitude 0 m) and extending upward to the entrainment zone – starting at approximately 1900 m. This is the region where the backscattered signal is nearly constant in amplitude with increasing altitude. The entrainment layer is the interface between the mixed layer and the free atmosphere, which demonstrates fewer particles with a correspondingly lower signal level.

The BL-View program processes the history of these profiles to identify and report up to 3 mixing layers (if detected) for each hour. The signal processing techniques are described in the BL-View manual available from through the Vaisala product support department. A sample time-height presentation of the aerosol scattered signal profile is shown in Figure 5.

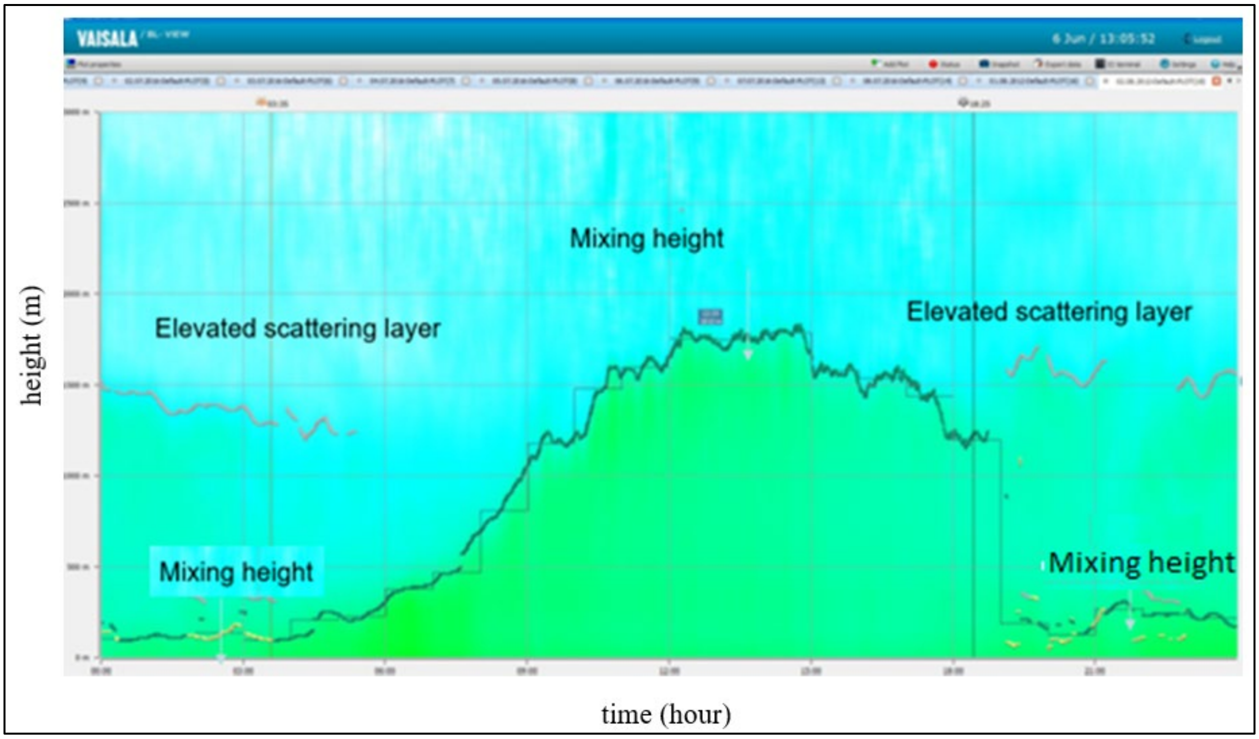

Figure 5: Diurnal variation of the ceilometer backscattered signal intensity

In Figure 5, the time of day increases from left to right on the x-axis and the altitude associated with the signal intensity at each point in time is scaled on the vertical axis. The signal intensity is then color encoded at each point. Greater backscatter intensity is shown in green and lower backscatter intensity is shown in blue. The resulting diurnal pattern illustrates the mixing height changes during the day. In general the mixing height is at lower altitudes in the morning and evening. The morning solar insolation heats the ground with the result that ground formed thermals initiate a vertical mixing process that mixes the particulate matter upward which causes the mixing layer to grow upward until early afternoon. Solar heating decreases in the afternoon with the result that the mixing layer begins to collapse in the afternoon and results in disconnected elevated scattering layers in the late afternoon which sometimes continues into the next day. The nocturnal mixing layer reforms close to the ground near and after sunset due to the cooling of the earth's surface. In effect, the scattering intensity time-height cross-section is a powerful visualization of the diurnal evolution of the atmospheric BL.

3.3. Instrument components

Ceilometer interior parts and components referenced in this SOP are identified in Figure 6

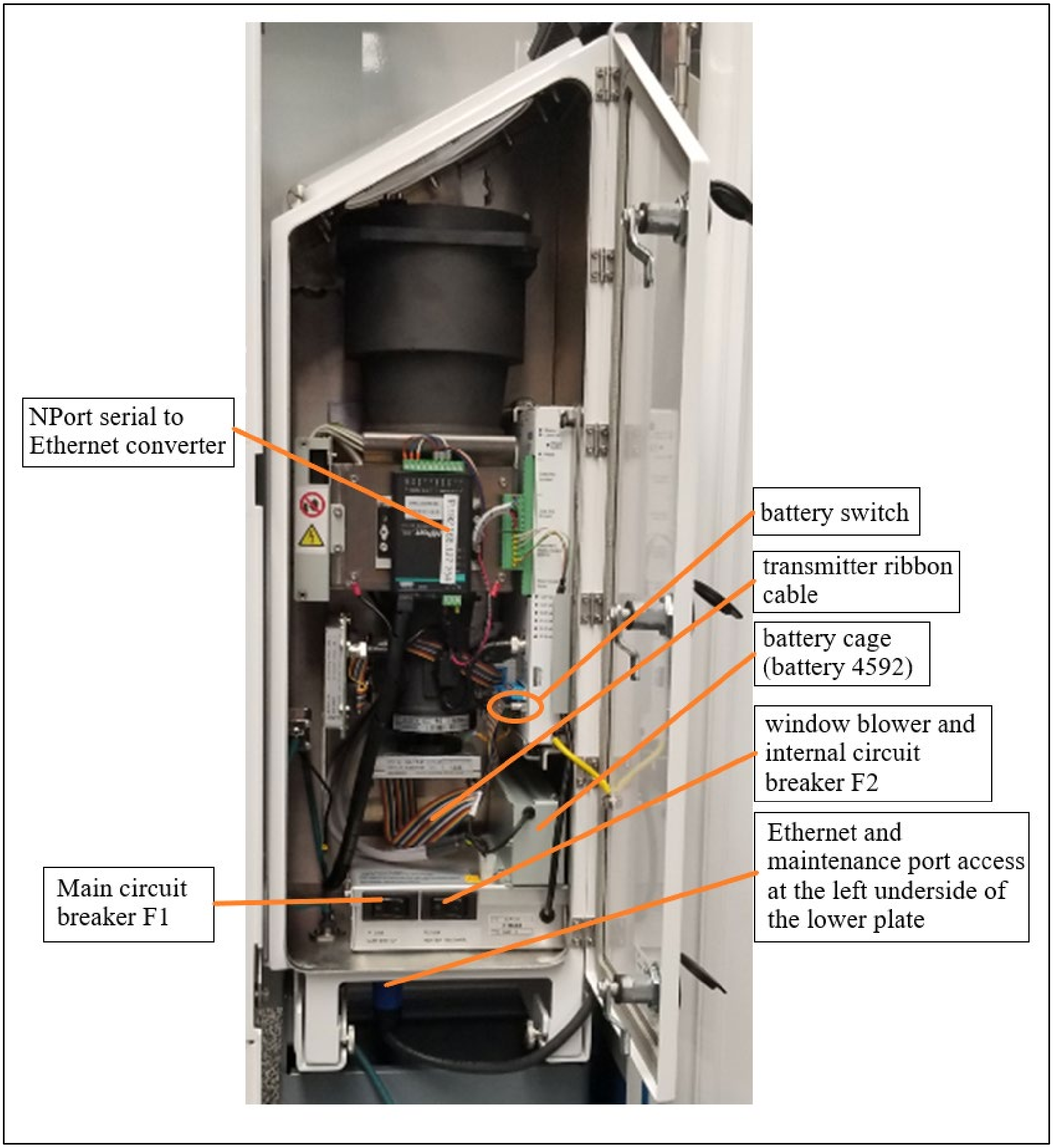

Figure 6: CL51 Measurement Unit Interior

4. Site Selection and Installation

The ceilometer should be securely installed on a stable level surface such as a concrete pad or wooden platform suitably located to provide an unobstructed view of the sky. The ceilometer must be installed so that the light beam points vertically with a clear view of the sky above it. Avoid installation adjacent to tall trees, bushes, overhead lines, antennas or other obstructions within the 2-degree viewing cone. Care should be taken that no obstructions can be blown into the ceilometer's field of view, such as tree limbs, loose metal covers, etc., as they will interfere with measurements.

For CL51 installation and BL-View Installation procedures, please refer to the Vaisala Ceilometer CL51 User Guide.

5. Operation

The CL51 has two operation modes, normal and standby. In the normal mode, continuous measurement and message transmission occurs according to the chosen parameters. The standby mode, which involves turning off the wearing parts, can be used during periods when measurement is not needed. The ceilometer should be kept in the normal mode.

Vaisala's Boundary Layer View (BL-View) software automatically calculates hourly average mixing height.

For more information on operation procedures, please refer to the Vaisala Ceilometer CL51 User Guide and Vaisala Boundary Layer View (BL-View) User Guide.

6. Data Management

BL-View is a dual function software package that provides control of the CL51 and logs and analyzes data from the CL51. BL-View archives raw signal data files which can be accessed manually at a later date. BL-View creates three file types: image, netCDF, and ASCII text files.

Image files capture the raw laser pulse data as a height vs. time plot figure similar to that shown in Figure 5. Image files include timestamped received signal intensity information from each laser pulse and are archived for users to evaluate offline.

The BL/mixing height measurements produced by the BL-View software package from the image files are recorded simultaneously in both netCDF and text file formats. The structure of and information contained within the netCDF files are discussed in the Vaisala technical reference document entitled "netCDF example file". For more information on HIS files and other file types, please refer to the Vaisala Ceilometer CL51 User Guide

Ecology's ceilometer PCs should be connected to the University of Maryland Baltimore County's (UMBC) unified ceilometer network (https://alg.umbc.edu/ucn/). HIS data files will be transferred to UMBC using a python script for FTP transfers. In addition to being able to send the last produced data file, the upload script has code that checks if any files are missing from the past seven days. If a file has not been previously uploaded to the server yet exists on the local computer, the missing file is transferred to the server. The upload scripts run once a day through setting a Windows Task scheduler task.

Once the data is received at UMBC it is stored in the ALG server and backed up to cloud servers periodically. After the server receives data to an ALG_FTP directory, it transfers the data to the directory ALG_ARCHIVE. ALG_ARCHIVE is not accessible to external users like initial ALG_FTP directory. Within ALG_ARCHIVE, each site is organized so that it has its own folder. Within each site folder, data is sorted by date folders. The path will generally follow "ALG_ARCHIVE\CEILO-

XX\YYYY\MM\DD\". The data in this pattern is raw, unaltered data directly from the ceilometer. Archive plotting for daily images begins at 1:00 UTC and plots the previous day's data.

7. Quality Control (QC)

Quality control checks are used to understand and ensure data quality. Instrument warnings and alarms should be checked daily. The window cleaning should be completed at least every 90 days. Diagnostics data on laser, a detector, and optics status will be checked monthly.

8. Quality Assurance (QA)

NOTE: A hard target test is not possible at Beacon Hill and are waiting on further guidance from the EPA on an alternative.

Quality Assurance (QA) performance evaluations are conducted every year by quality assurance personnel. Performance audits are conducted by performing a hard target comparison. The auditor should be independent of the normal operations of the site. Results of the audit should be obtained from the same data acquisition system that is used for daily data retrieval and storage. It is recommended that the audit is performed on an annual basis.

9. Equipment Calibration

No field calibration is currently required for ceilometers.

10. Maintenance

The CL51 comprises few moving parts and requires little routine maintenance. In general, the most important maintenance function is to ensure an unobstructed view and a clean window for the laser beam. The ceilometer performs best (strongest signal transmission and reception) with a clean window. Routine frequent maintenance includes checking for operational alarms and warnings, cleaning the window, and checking the door gasket. The backup battery should be checked annually, and the laser window contamination system should be recalibrated after five years of use. These procedures are described below.

10.1. Alarms and warnings

The data message must be checked for alarms and warnings on a regular basis. The second character in line two contains warning and alarm information indicating the present device status as follows:

0	Self-check OK
W	At least one warning active, no alarms
A	At least one alarm actives

When there is an active alarm or warning, more information is given at the end of the second line in the data message as a binary code indicating the cause. The status message provides detailed information about the failure.

Refer to Tables 22 and 23 in the CL51 manual for details of warning and alarm messages. Contact Vaisala product support for warnings or alarms that require repair or servicing of the CL51. Repair and service must be done according to the instructions in the CL51 Users Guide.

10.2. Cleaning the CL51 window

The CL51 checks the window blower hourly and will notify the user of a contaminated window or operational error with an alarm in the data messages. The system will activate the window blow if contamination is detected, to remove light contaminants and dry water droplets. If the blower is unable to sufficiently remove contamination, the CL51 will issue a "Window Contaminated" warning to notify the operator that the window must be manually cleaned per the following steps:

1. Keep the enclosure door closed and gently flush the window with clean water to remove coarse grains. Do not use a pressure cleaner to clean the window.
2. Clean the enclosure door closed and gently flush the window with clean water to remove coarse grains. Do not use a pressure cleaner to clean the window.

The window blower operation should be verified while cleaning the window. Unless already running, the blower should start when you block the laser beam (cover the laser window) with the cleaning cloth for approximately 15 seconds or more. The blower should stop after the window is cleaned unless there are low clouds, precipitation, or fog present. If the window blower does not activate or properly cease to run, the blower may be defective and require replacement. Contact Vaisala customer support for further troubleshooting on the window blower.

10.3. Checking door gasket

The measurement unit door utilizes an electrically conductive gasket to suppress electromagnetic radiation. When the door is opened, check that the gasket and the opposite contact surfaces are clean. If necessary, use a wet cloth for cleaning.

10.4. Checking battery

Check the battery condition annually. Replace the battery if you observe any signs of aging such as a bulging battery case, white powder or residue near the battery vent, leaking electrolyte, or corroded terminals. Lead acid batteries may degrade and result in a rupture and loss of electrolyte after 3 to 5 years of service.

10.5. Window contamination measurement calibration

After 5 years of operation, the CL51 may more frequently issue window contamination warnings as the result of window contamination measurement drift or wearing of the laser window, requiring replacement. The window contamination measurement should be calibrated before replacing the window. Calibration is described in detail in the CL51 user manual.

After attempting a calibration, if the window contamination warnings continue to be issued, contact the Vaisala product support staff for further guidance on replacing the window.

10.6. Troubleshooting

The BL-View software interface has an icon adjacent to the ceilometer icon in the upper left side of the main screen that indicates the system status or operational alerts.

To view the active alerts, select the alerts menu option in the main window. The active alerts will be listed in a table along with their severity and the time at which the condition alert was detected. For each alert there is a corresponding identifier and a help option to assist the operator to address the alert. An example of the alert table is shown in Figure 7.

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 7: BL View alerts

A complete discussion of each alert, their corresponding meanings, and the recommendation to correct the alert is found in Chapter 11 of the BL-View user manual3. To summarize, these alerts are used to monitor the following system functions:

- BL View software operational status
- Ceilometer hardware status
- Communications status with the Ceilometer
- System errors

In addition to the system warnings provided through the alert feature within the BL-View software, more detailed inspection of the system components is available outside the BL-View interface by using a terminal program such as TeraTerm5 coupled with a serial connection to the Ceilometer maintenance port (J4) at the bottom cable entrance to the ceilometer using a terminal connection to the ceilometer. Since most modern computers do not have serial port connections, a USB to serial connection cable may be needed for this connection. Vaisala customer support should be contacted before attempting to use this feature. Please refer to the Vaisala BL-View manual when using this feature.

11. Data Validation

Mixing height layer data will be reviewed and validated by the University of Maryland Baltimore County's (UMBC) unified ceilometer network (https://alg.umbc.edu/ucn/). UMBC use an automated planetary boundary layer height (PBLH) retrieval algorithm that uses aerosol backscatter signal without the need for additional measurements. The PBLH algorithm reports a PBL height and uncertainties. The algorithm first addresses aerosol backscatter signal quality and applies corrections and signal smoothing to aerosol backscatter profiles. The algorithm then screens signals for precipitation and clouds, followed by the application of the Haar wavelet transform on aerosol backscatter profiles. Details for the comprehensive algorithm can be found in Caicedo et al. (2020). All ceilometer data are binned according to ceilometer reported temporal resolution to account for any gaps in data. For example, each daily file for the Vaisala CL31 ceilometer should contain 5760 profiles with each bin increasing from 0000 to 2359 UTC every 15 s. If no measurement was reported, the bin will remain empty. All vertical values are reported in meters above ground level (AGL).

The mixing height data generated by BL-View contain data quality indexes for each reported height, as well as for the reported 1-hour mixing height. These indexes range from 1 to 3, with "1" indicating poor quality, "2" indicating marginal quality, and "3" indicating good quality. Vaisala has recommended that data with a quality index of "2" or "3" be considered valid, whereas data with a quality index of "1" should not be considered valid without further review. As of publication of this SOP, the convention for reporting hourly MLH data to AQS is still under development. It is anticipated that all data should be submitted to AQS, and that the submission for each hour will include both the hourly mixing height and its associated quality index. Users (i.e. modelers) can then decide as to the use of the poorer quality data.

12. Data Quality Assessment

For each calendar quarter and year, the Quality Assurance Unit will prepare a data quality assessment (DQA) report. The results of the DQA are used to regularly evaluate the effectiveness of meteorological monitoring systems and processes within the Washington network and inform improvements.

Data completeness

Data completeness is determined for each parameter and will be expressed as a percentage. Percent valid data will be a gauge of the amount of valid data obtained compared to the amount expected under ideal conditions (24 hours/ day, 365 days/ year). As required by EPA:

- Hours with less than 75 percent* of their minute data valid are not considered valid.
- Days with less than 75 percent* of their hourly data valid are not considered complete.
- Quarters with less than 75 percent* of their days complete are not considered complete.

* NOTE: The Washington network has set a goal of 80 percent data completeness quarterly and annually.

13. References

Air Monitoring Project Approval, Site Selection, and Installation Procedure. WA Department of Ecology/Publication 16-02-021 November, 2019.

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Technical Assistance Document for Sampling and Analysis of Ozone Precursors for the Photochemical Assessment Monitoring Stations Program – Revision 2. EPA-454/B-19-004. April, 2019.

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Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV-Meteorological Measurements Version 2.0. EPA-454/B-08-002 March, 2008.