A: Project Management and Information/Data Quality Objectives

A1: Title Page

U.S. Environmental Protection Agency
Office of Research and Development
Center for Environmental Measurement and Modeling
Atmospheric & Environmental Systems Modeling Division
Natural Systems Characterization Branch

Unified Ceilometer Network in support of the US EPA Photochemical Assessment Monitoring Stations
Quality Assurance Project Plan (QAPP)

ORD National Program: Air, Climate and Energy

Version Date: April 22, 2025

Project QAPP ID: J-AESMD-0033586-QP-1-0

QA Category: A ☐ B ☒

QAPP Developed:	☒ Intramurally:	Period of Applicability for intramural QAPPs starts on the date of QAPP approval and ends five years after QAPP approval date or until a new version of the QAPP is approved, whichever is sooner.
	☒ Extramurally:	**Vehicle #:** MOU (NASA) **Name of Non-EPA Organization:** Hampton University **Period of Performance (POP):** 2025 - 2029 Period of Applicability for extramural QAPPs starts on the date of QAPP approval and ends on the last day of the POP or until a new version of the QAPP is approved, whichever is sooner, and not to exceed 5 years.

QAPP Accessibility: *QAPPs will be made internally accessible via the ORD QAPP intranet site upon final approval unless the following statement is selected.*

☐ I do NOT want this QAPP internally shared and accessible on the ORD intranet site.

Project Discipline Type(s) (check all that apply):

☐ Code Based Modeling
☒ Measurements and Monitoring
  ☐ Analytical Methods Development
  ☐ Animal/Cell Culture Studies
☐ Software and Application Development
☐ Environmental Technology
☐ Model Application and Evaluation
☐ Other________________________
☐ Existing Data
☐ Social Science

A2: Approval Page

QAPP Approvals (Electronic Approval Signatures/Dates)

ORD Technical Lead (TL):	JAMES SZYKMAN Digitally signed by JAMES SZYKMAN Date: 2025.06.10 15:06:35 -04'00'	Jim Szykman
ORD Alternate Technical Lead (TL)	ERIC BAUMANN Digitally signed by ERIC BAUMANN Date: 2025.06.10 15:12:42 -04'00'	Eric Baumann
ORD Technical Lead's Supervisor:	CAROL LENOX Digitally signed by CAROL LENOX Date: 2025.06.10 15:35:09 -04'00'	Carol Lenox
ORD QA Manager[1]:	WENDY COSS Digitally signed by WENDY COSS Date: 2025.06.13 09:39:04 -04'00'	Wendy Coss
OAQPS PAMS Co-Lead:	Hillis, Berkley Digitally signed by Hillis, Berkley Date: 2025.06.11 07:43:08 -04'00'	Berkley Hillis
OAQPS PAMS Co-Lead	ELIZABETH GOOD Digitally signed by ELIZABETH GOOD Date: 2025.06.11 07:54:43 -04'00'	Elizabeth Good
OAQPS QA Lead:	DIYA YANG Digitally signed by DIYA YANG Date: 2025.06.11 09:34:54 -04'00'	Diya Yang

Extramural Approvals

Hampton University Center for Atmospheric Sciences:		Ruben Delgado
Hampton University Center for Atmospheric Sciences:	JOHN MCNABB	John McNabb

[1] The approval date of the QAPP is the date of EPA QA Manager approval unless otherwise specified.

Disclaimer:
Mention of commercial products or trade names will not be interpreted as an endorsement. Some types of instruments currently in use may be described in the text or example figures or tables. Sometimes these products are given as a typical and perhaps well-known example of the general class of instruments. Other instruments in the class are available and may be fully acceptable.

Forward:
This Quality Assurance Project Plan (QAPP) is associated with the PAMS Required Network QAPP EPA-454/B-19-003, Photochemical Assessment Monitoring Stations (PAMS) Required Site Network for the parameters of speciated volatile organic compounds (VOCs), carbonyls, and meteorological measurements including mixing layer height (MLH). This QAPP covers monitoring agencies operating ceilometers for the required MLH and sending their data to the Unified Ceilometer Network, a joint effort between the EPA and Hampton University to provide a national data archive of ceilometer data and common data processing for the determination of MLH as required by PAMS. The scope of this QAPP is intended to cover the data transmission from PAMS sites to the UCN, assessment of the data quality through the use of available instrument diagnostic, post-processing of the ceilometer backscatter data, and generation, archival, and distribution of MLH and non-required ancillary data products.

The UCN was developed to ease the burden on state and local air monitoring agencies in the processing of ceilometer attenuated backscatter data to determine an MLH. The UCN provides a common infrastructure to fully exploit the capabilities of ceilometers and harmonize ceilometer data streams from PAMS and non-PAMS sites using scientifically peer-reviewed algorithms and instill greater confidence in the use of the data by users.
Monitoring agencies should use the information in this QAPP to update agency specific QAPPs which deal with ceilometers and the UCN.

A3: Table of Contents, Document Format, and Document Control

Table of Figures

Table of Tables

Revision History

Date	QAPP ID	Author(s)	Description of Revision
April 22, 2025	J-AESMD-0033586-QP-1-0	Jim Szykman	Initial Approved Version

Acronyms/Abbreviations/Definitions

Acronym/Abbreviation	Definition
ADQ	Audit of data quality
AGL	Above ground level
AQS	Air Quality System
AWS	Amazon Web Services
CAA	Clean Air Act
CBI	Confidential Business Information
CFR	Code of Federal Regulations
CWTC	Covariance Wavelet Transform Coefficients
DQO	Data Quality Objective
EMP	Enhanced monitoring plan
EPA	Environmental Protection Agency
EIO	Environmental Information Operations
HU	Hampton University
IP	Implementation plan
km	kilometer(s)
Lidar	LIght Detection And Ranging
m	Meter(s)
min	Minute(s)
MLH	Mixing layer height
NAAQS	National ambient air quality standard
NBL	Nocturnal boundary layer
OAQPS	Office of Air Quality Planning and Standards
ORD	Office of Research and Development
OS	Operating System
PAMS	Photochemical assessment monitoring station
PBL	Planet boundary layer
PBLH	Planetary boundary layer height
PII	Personally Identifiable Information
PM	Particulate matter
PPM	Policy & Procedures Manual
QA	Quality Assurance
QAIP	Quality assurance implementation plan
QAM	Quality Assurance Manager

QAPP	Quality Assurance Project Plan
QC	Quality Control
QMP	Quality Management Plan
QS	Quality system
Quality Assurance	Management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected.
Quality Control	Technical activities that measure the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements
RL	Residual layer
SLT	State, local, or tribal (monitoring organization)
SNR	Signal to noise ratio
SOP	Standard Operating Procedure
TL	Technical Lead
UCN	Unified Ceilometer Network

A4: Project Purpose, Problem Definition, and Background

Environmental information operations (EIO) conducted under this Quality Assurance Project Plan (QAPP) will adhere to the requirements specified in the Office of Research and Development (ORD) Quality Management Plan (QMP).

A4.1: Project Background

Reducing tropospheric ozone pollution requires reducing or eliminating emission sources of VOCs and oxides of nitrogen. Modelers predict the production of ground-level ozone by running complex models which are continually refined to better estimate the ozone under various meteorological conditions.

A4.2: Project Purpose and Problem Definition

The objectives of the UCN is to:

- Develop and implement a centralized data archive of attenuated backscatter coefficient profiles β(z) from ceilometers within the U.S. Air Quality Network.
- Implement a common algorithm to produce a set of quality-controlled outputs from the ceilometer β(z), including a consistent mixing layer height (MLH) measurement to characterize biases and uncertainties of hourly MLH in chemical transport models used to estimate the ozone concentration under various meteorological conditions and air quality episode analyses for air quality planning and management.
- Serve as a reporting option for the U.S. EPA PAMS program (Technical Note - Participation in the Unified Ceilometer Network, August 30, 2021) as MLH is a required observable under the Photochemical Assessment Monitoring Station Program . (Appendix D to Part 58, Title 40).

A5: Project Task Description

The goal of this project QAPP is to provide consistent processes for:

- Data processing of ceilometer aerosol backscatter data
- Minimum quality assurance requirements
- Production of hourly mixed layer heights for SLT air quality agencies who voluntarily join the UCN

To increase the science and application uses of data products by leveraging PAMS and non-PAMS ceilometers in one central local, the UCN will also provide additional data products not required by PAMS.

Advanced Data Products

- Real-time data display of aerosol backscatter profile plots
- Real-time data processing (MLH, Nocturnal Boundary Layer (NBL), residual layer (RL), aerosol layers, Clouds, and precipitation screening)
- Data archive download and display

Operational Procedures for Quality Control:

- Instrumental signal evaluation
- Standardized retrieval development
- Data archiving and processing
- Real-time optics monitoring

Table 1 below lists expected tasks and products for this project in relation to their anticipated start and projected end dates by Fiscal Year (FY).

Table 1. Project Completion Timeline

Project Task Schedule	**FY25**	**FY25**	**FY25**	**FY26**	**FY26**	**FY26**	**FY26**	**FY27**	**FY27**
Task Description	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**
QAPP Preparation and approval	X				X				
Establish data transfer from UCN sites	X	X							
Create and maintain UCN website		X	X	X	X				
Implementation of Harr wavelet algorithm for new UCN data products	X	X	X	X	X	X	X	X	X
Create UCN subsetter and related code					X	X	X	X	X

A6: Information/Data Quality Objectives and Performance/Acceptance Criteria

The overall research objective is to generate automated and robust hourly ML retrievals of long-term heterogeneous data sets through signal correction, cloud and precipitation screening, uncertainty calculation, and automated filtering.

The Data Quality Indicator goals for accuracy, precision, and completeness for the UCN are summarized in Table 2. The Data Quality Indicators (Table 2) were derived from an evaluation of the Haar wavelet algorithm (Caicedo et al., 2020) which has been incorporated in the UCN processing software. To ensure the accuracy and reliability of MLH retrievals, the following quality control measures are implemented within the processing software:

1. Standard Deviation Thresholding – Retrievals with a standard deviation exceeding 200m are excluded to enhance data quality and reduce uncertainty.
2. Precipitation Filtering – Planetary boundary layer height (PBLH) retrievals identified during precipitation events are automatically removed to prevent contamination of the dataset.
3. Cloud Contamination Mitigation – Cloud presence can affect retrieval accuracy by attenuating aerosol backscatter above the cloud layer or enhancing signals below the cloud base. To address this:
    a. If a cloud base height (CBH) is detected within 300 m of the identified PBLH, the PBLH value is removed.
    b. In cloud-topped mixed layers, where PBLH is equivalent to CBH, only CBH is reported.
4. Final Data Reporting – After applying all quality control checks, final 10-minute retrievals are reported, along with their standard deviations, to ensure robust and automated outputs.
5. Supporting Data for Interpretation – In addition to standard PBLH retrievals, aerosol backscatter profiles are utilized to provide further context for interpreting PBL vertical structure and aerosol layering.

Table 2. Unified Ceilometer Network Data Quality Indicators

Measurement / Retrieved Parameter	Analysis Method	PAMS Derived Parameter	Sampling Frequency	QC Check	Precision	Completeness
Mixing Layer Height	Haar wavelet algorithm	Hourly Mixing Layer Height	10 min average MLH generated as common sample frequency	Visual check of data and products using aerosol backscatter and MLH	± 200 m	50%
Residual height layer	Haar wavelet algorithm	Hourly Residual Layer Height	10 min average MLH generated as common sample frequency	Visual check of data and products using aerosol backscatter and MLH	± 200 m	50%
Aerosol Backscatter	Manufacturers instrument software	**Non-PAMS derived parameter**	Varies by ceilometer 15-36 seconds	Visual check of data and instrument diagnostics monitoring	± 10 m	NA
Aerosol layers	Haar wavelet algorithm	**Non-PAMS derived parameter**	10 min average generated as common sample frequency	Visual check of data and uncertainty evaluations	NA	NA
Cloud heights	Haar wavelet algorithm	**Non-PAMS derived parameter**	10 min average generated as common sample frequency	Visual check of data and products using aerosol backscatter	NA	NA
Precipitation	Haar wavelet algorithm (measure properties of image regions)	**Non-PAMS derived parameter**	10 min average MLH generated as common sample frequency	Visual check of data and products using aerosol backscatter	NA	NA

Section B provides the details necessary for the setup, operation, and maintenance of the ceilometer to achieve these data quality indicators.

A7: Distribution List

The EPA Technical Lead (TL) is responsible for maintaining a copy of the original approved QAPP and all approved subsequent revisions of the QAPP within their project file. The Technical Lead (TL) is responsible for the distribution of the most current signed approved version of the QAPP to participants as indicated in Table 3 below. QAPP revisions are controlled through QA Track. The signed QAPP will be posted on the EPA PAMS website (https://www.epa.gov/amtic/photochemical-assessment-monitoring-stations-pams#guidance) and the UCN website (https://www.ucn-portal.org/).

Table 3. Distribution List

Name & Organization	Contact Information (e-mail)	Project Role(s)
Wendy Coss EPA/ORD/CEMM/AESMD/IO	Coss.wendy@epa.gov	QA Manager (QAM)
Carol Lenox EPA/ORD/CEMM/AESMD/NSCB	Lenox.carol@epa.gov	Branch Chief
Jim Szykman EPA/ORD/CEMM/AESMD/NSCB	James.j.szykman@nasa.gov	Technical Lead (TL) / Project Lead (PL)
Eric Baumann EPA/ORD/CEMM/AESMD/NSCB	Baumann.Eric@epa.gov	Alternate Technical Lead (TL) / Project Lead (PL)
Berkley Hillis EPA/OAR/OAQPS/AQAD/AAMG	Hillis.berkley@epa.gov	PAMS Program Co-Lead
Diya Yang EPA/OAR/OAQPS/AQAD/AAMG	yang.diya@epa.gov	QA Lead
Elizabeth Good EPA/OAR/OAQPS/AQAD/AAMG	Good.elizabeth@epa.gov	PAMS Program Co-Lead
Ruben Delgado Hampton University Center for Atmospheric Sciences	Ruben.delgado@hamptonu.edu	UCN Technical Lead
John McNabb Hampton University Center for Atmospheric Sciences	John.mcnabb@hamptonu.edu	UCN Data Manager
Contact list provided by PAMS Program leads. EPA Regional Office EPA Regions 1 - 10	See contact list.	PAMS Program Quality Lead
State, Local, Tribe (SLT) PAMS Required Site Monitoring Agencies	See UCN application	Monitoring agency

A8: Project Organization

The UCN is a voluntary network focused on creating a national archive for ceilometer data. The network provides a common data processing framework for ceilometer backscatter profile data for calculating hourly MLH along with other added value data products for use by the EPA and state, local and Tribal (SLT) air monitoring agencies, but is open to any user. SLT monitoring agencies who join the UCN will satisfy their requirement to collect and report an hourly mixing level height as one of the required measurements under PAMS under 40 Code of Federal Regulations (CFR) Part 58 Appendix D Section 5(b).

Organizations essential to the operation of the UCN include HU, SLT monitoring agencies, EPA ORD, EPA Regions and EPA OAQPS. The communication and responsibility structure for the UCN is depicted in Figure 2.

The roles and responsibilities of individuals involved in performing research activities and developing products within this project are identified below in Table 4.

Table 4. Environmental Information Roles and Responsibilities

Name & Organization	Project Role(s)	Project Responsibilities
Wendy Coss EPA/ORD/CEMM/AESMD	QA Manager	• Provides QA training/review for AESMD on the ORD QA Program. • Assists the ORD TL in ensuring that quality requirements are identified for the project. • Reviews and approves QAPP. • Reviews and approves ORD sub-products and products developed under the project QAPP. • Reports quality related issues to the TL's supervisor and organization's senior manager.
Carol Lenox EPA/ORD/CEMM/AESMD/NSCB	Branch Chief	• Consults with TL and QAM on QA category designation. • Reviews and approves QAPP. • Communicates regularly with project TL to ensure that QA requirements are met. • Evaluates and seeks to provide the necessary resources to accomplish the work described in the QAPP. • Ensures that no EIO begins until the QA documentation is approved.
Alan Vette EPA/ORD/CEMM/AESMD/IO	Division Director	• Provides the necessary resources (personnel, funding, materials, supplies, and time) to accomplish the work described in the project QAPP. • Ensures the roles and responsibilities of division personnel meet project specific and organizational specific requirements as specified in QAPPs and the ORD QMP.
Jim Szykman Eric Baumann (Alternate) EPA/ORD/CEMM/AESMD/NSCB	UCN Technical Lead / Project Lead	• Maintains and distributes the official, approved copy of this QAPP to project EIO participants. • Reviews project QAPP annually for consistency with the current EIO of the project and updates the QAPP to match the current EIO of the project as necessary. • Notifies their QAM in writing of any quality related issue or deviation from QA documentation. • Works with HU, OAQPS, and the Regional Offices to assess training needs for SLT agencies and assist in the development and training for the UCN. • Conducts research on UCN algorithms, including evaluation of algorithm improvements in conjunction with UMBC, and provides EPA approval for any algorithm updates to the UCN • Participates in the PAMS Required Site Network Workgroup • Prepares, distributes, and maintains UCN executable files for each site • Processes new applications for sites joining the UCN • Works with SLT tribal agencies to establish initial and on-going data transfer to UCN servers.

Name & Organization	Project Role(s)	Project Responsibilities
		• Selects and purchases instrument to measure PAMS required MLH parameter • Identifies and provides statement of concurrence for validated data provided by the UCN into AQS in accordance with the protocols described in this QAPP and the AQS Coding Manual • Maintains and operates UCN in accordance with QAPP • Suggests updates to the monitoring agency PAMS QAPP as necessary to reflect connection with UCN QAPP
Berkley Hillis, ,Elizabeth Good & Diya Yang EPA/OAR/OAQPS/ AQAD/AAMG	PAMS Program Co-Leads and QA Lead	• Leads PAMS program • Coordinates and provides any updates to the national PAMS QAPP • Schedules and runs required Site Network Workgroup • Reviews and provides input to UCN QAPP • Informs ORD and HU of new required PAMS sites. • Works with Regions and SLT agencies to communicate updates provided from the UCN to OAQPS • Suggest updates to UCN QAPP as necessary to reflect connection with monitoring agency PAMS QAPP • Contract support for audits of equipment at SLT monitoring agencies in conjunction with EPA Region Offices
Ruben Delgado & John McNabb Hampton University Center for Atmospheric Sciences	UCN Technical Lead	• Develops, operates, and maintains the UCN, generating hourly mixing level heights for each SLT agency proving ceilometer data into the UCN, verifying the quality of the hourly MLH data, and generation of a standardized data file that can be used to report to AQS • Participates in the PAMS Required Site Network Workgroup • Reviews and provides input to UCN QAPP • Prepares, distributes, and maintains UCN executable files for each site • Processes new applications for sites joining the UCN • Works with SLT tribal agencies to establish initial and on-going data transfer to UCN servers • Selects and purchases instrument to measure PAMS required MLH parameter • Identifies and provides a statement of concurrence for validated data provided by the UCN into AQS in accordance with the protocols described in this QAPP and the AQS Coding Manual • Maintains and operates UCN in accordance with QAPP • Suggests updates to the monitoring agency PAMS QAPP as necessary to reflect connection with UCN QAPP
(TBD) EPA Regional Offices	PAMS Program Quality Lead	• Led the implementation of PAMS Program and Quality Assurance program, including approval of SLT QAPPs • Administers Quality System in consultation with EPA OAQPS and ORD • Conducts audits of equipment at SLT monitoring agencies • Approved SLT agencies PAMS Enhanced Monitoring Plans

Name & Organization	Project Role(s)	Project Responsibilities
		• Reviews and provides input to UCN QAPP • • Works with SLT agencies to communicate necessary updates provided on the UCN
SLT PAMS Required Site Monitoring Agencies	Monitoring Agency	• Acquires ceilometers, provides and trains appropriate staff, operates instruments, and sends the ceilometer data on an agreed-upon frequency to the UCN • Participates in the PAMS Required Site Network Workgroup • Reviewing and providing input to UCN QAPP • Selects and purchases instrument to measure PAMS required MLH parameter • Submits application to join the UCN • Installs and tests the ceilometer and ancillary support equipment to meet the requirements to provide data to the UCN • Works with UCN personnel to establish data transfer to UCN • Provides a statement of concurrence for validated data provided by the UCN into AQS in accordance with the protocols described in this QAPP and the AQS Coding Manual • Maintains and operates ceilometer in accordance with monitoring agency QAPP • Updates the monitoring agency PAMS QAPP as necessary to reflect connection with UCN QAPP and submits for EPA Regional review and approval

A9: Project Quality Assurance Manager Independence

ORD QA Managers are independent from all Environmental Information Officers (EIO) for any project for which they serve as Project QA Manager for, as indicated in the ORD QMP and Table 5 within Section A8 of this QAPP. Figure 1 in Section A10 shows the independence of the ORD Project QA Manager from project participants and EIO within this project.

A10: Project Organizational Chart and Communications

Figure 1 and Figure 2 organizational/communication charts provide a visual representation of the working relationships and lines of communication among all project participants identified in Table 3. Any issues identified by an individual within the project will notify the TL. The TL will notify their QA Manager in writing of any quality related issue or deviation from QA Documentation. The QA Manager has the authority to access and discuss quality related issues with their organization's senior manager.

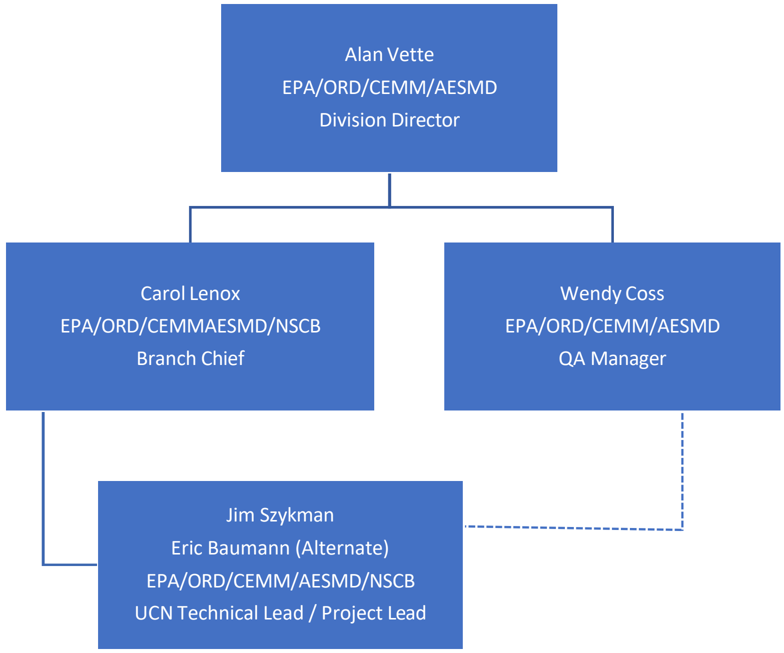

Figure 1. Project Organizational Chart

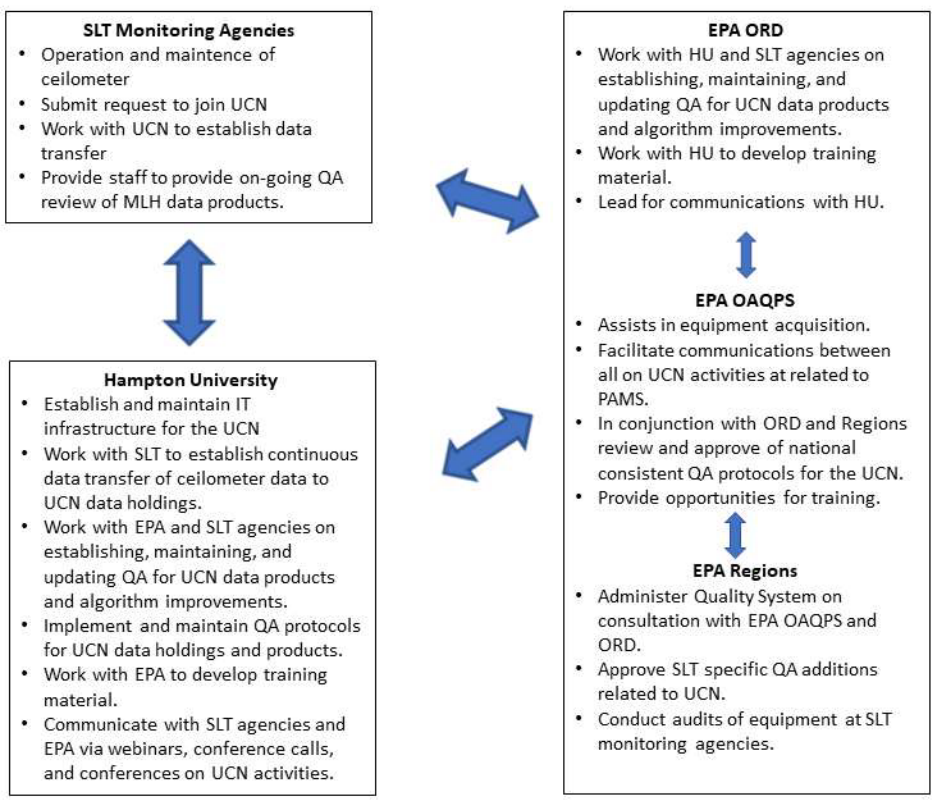

Figure 2. PAMS-UCN Site Network Communication and Responsibility Structure

A11: Personnel Training/Certification

Basic training material on ceilometer operation and maintenance will be developed to enhance existing material developed by OAQPS and their PAMS QA support contractors. Training material will be developed and updated on use of the UCN, including data submission, retrieval, and best practices on data use/interpretation. UCN specific training material will be hosted on the UCN website. The uptake of training material by each organization involved in the UCN is optional, as there is no specific training required to participate in the UCN. Specialized expertise and qualifications needed to be a PI or Technical Lead in this project include an advanced level of graduate training (M.S. or Ph.D.) and experience in the fields of meteorology, physics, chemistry, earth science, atmospheric science, engineering, and/or related fields. Staff members who participate in this project must be able to apply theory, practices, and analysis methods on advanced principles of atmospheric structure, in particular boundary layer meteorology, and remote sensing; including the basic principles of Light Detection And Ranging (LIDAR) for measuring the atmosphere and application of such measurements to interpret meteorology, atmospheric chemistry, or physics as related to boundary layer dynamics and air quality; and use statistical techniques to analyze measurement data results. To perform these functions, individuals generally need to be proficient in the current computer environments (e.g., Linux/Unix) and languages (e.g., FORTRAN and R) used in scientific computations and analysis. The PI is responsible for assuring that any additional training needed is completed and documented in the project notebook.

A12: Documents and Records

Table 5 provides a list of documents and records that will be generated for this project, the parties responsible for generating and updating those records, storage locations, and file types. The ORD technical lead will be responsible for maintaining a copy of all file records in accordance with the EPA records schedule identified in Table 6.

Table 5. Documents and Records

Record Type	Responsible Party	Located in Project File (Y/N) If No, Add File Location Below	File Type (Format)	Special Handling Required (Y/N)
QAPP	Jim Szykman	Y C://user/jszykman/documents/PAMS/UCN/QAPP	PDF	N
Summary File	Jim Szykman	C://user/jszykman/documents/PAMS/UCN	WORD	N
UCN applications from SLT agency	Jim Szykman / HU	Maintained by HU with copy available on PAMS workgroup TEAMS site	PDF	N
UCN site status tracking	Jim Szykman / HU	Maintained by HU with copy available on PAMS workgroup TEAMS site	Excel	N
Ceilometer data*	Jim Szykman / HU	HU UCN servers	NetCDF, HIS (ASCII), and jpg (or) png	N

Record Type	Responsible Party	Located in Project File (Y/N) If No, Add File Location Below	File Type (Format)	Special Handling Required (Y/N)
Records for proof-of-concept projects, method validation studies, or basic exploratory, conceptual research projects.	Jim Szykman/HU	Y C://user/jszykman/documents/PAMS/UCN	WORD, PDF, Excel, NetCDF	N
Instrument logbooks documenting routine maintenance, calibration, and repair of instruments.	State, Local, or UCN site	N, Site specific logbooks required by PAMS	Notebook (hard bound or electronic)	N

* Should the need arise to modify or move the processing system, HU will work with EPA to transition the UCN to an appropriate alternative organization of mutual agreement. Notification of the need to transition the system will be provided by either organization at least 6 months in advance.

Table 6. Project's Record Schedule

EPA Records No. and Series Title	Brief Description	Final Disposition	QA Category
☐**1035(a):** Historically significant environmental programs and project records	Applied and directed scientific research project files for projects conducted by EPA personnel in the Office of Research and Development (ORD) laboratories that directly support rulemaking, enforcement, regulatory, or policy decisions, research of high programmatic relevance, and research of significant national interest (e.g., technology transfer projects which may be critical to the award of a patent or other important commercial or legal decision), consisting of research plans, research methodology, questionnaires, quality assurance project plans, raw data, laboratory notebooks, correspondence, reports, peer reviews, quality assurance assessments, and related records.	Permanent	Cat **A**
☒**1035(b):** Long-term environmental program and project records	Includes records that are not required for documenting the history of the program or project, but which have operational value to EPA throughout the life of the program or project.	20 Years	Cat **B**

B: Implementing Environmental Information Operations

B1: Identification of Project Environmental Information Operations

The environmental information operations for the UCN are depicted in Figure 3 and involve three main components: data transfer from ceilometer sites, data processing of the ceilometer data, and data visualization and download capabilities of the processed data.

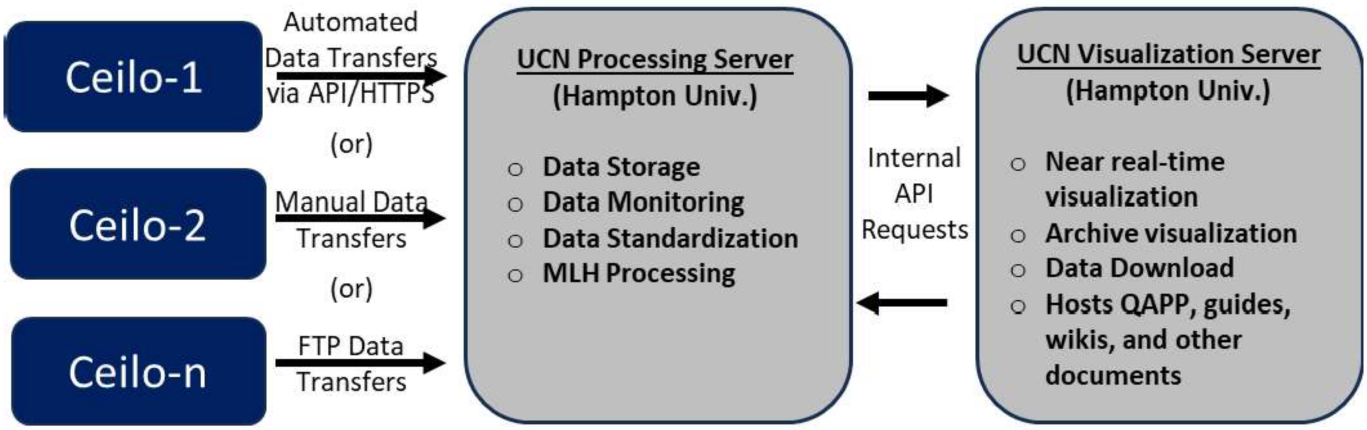

Figure 3. Unified Ceilometer Network Data Transfer and Processing

B1.1 Data Transfers

Agencies provide data to Hampton University through multiple secure transfer mechanisms to ensure efficient and reliable data acquisition. These methods include:

1. **Automated Data Transfers via API/HTTPS** – Data is transferred programmatically using secure API endpoints over HTTPS, enabling real-time or scheduled data ingestion with authentication and encryption protocols in place.
2. **Manual Uploads** – Agencies may also provide data through direct manual uploads to a designated secure portal maintained by Hampton University. This method is used for datasets that require additional review or processing before integration.
3. **FTP Transfers** – Secure File Transfer Protocol (FTP) is utilized for bulk data transfers, allowing agencies to deposit large datasets in a controlled and structured manner. Access credentials and encryption methods are implemented to maintain data integrity and security.

These transfer mechanisms ensure that Hampton University receives timely and high-quality data for analysis while maintaining compliance with data security and data management protocols.

B1.2 Data Processing Server Overview

The data processing server at Hampton University serves as a centralized system for managing, monitoring, and processing incoming datasets from various agencies. Key functions include:

1. **Data Storage** – The server securely stores incoming datasets, ensuring long-term availability and integrity. Storage solutions include structured databases and file repositories optimized for efficient retrieval and management.
2. **Data Monitoring** – Continuous monitoring of incoming and stored data is performed to track transfer statuses, detect anomalies, and ensure data completeness. Automated alerts and logging mechanisms provide real-time notifications of any issues requiring intervention.

3. **Data Standardization** – The format of the incoming datasets are unique to the manufacturer's software used to log and process the ceilometer data. Incoming files transferred to the UCN undergo a standardization process to ensure consistency across different formats, units, and metadata structures. This step facilitates seamless integration and comparability of data from multiple sources.
4. **Data Processing** – The server executes automated workflows to clean, analyze, and transform raw data into actionable formats. This includes quality control checks, format conversions, and derivation of key parameters required for research and reporting.

By implementing these core functions, the processing server ensures that Hampton University maintains a robust, scalable, and reliable data management infrastructure that supports atmospheric and environmental research initiatives.

B1.3 Visualization Server Overview

The visualization server at Hampton University provides an interactive and user-friendly platform for accessing, analyzing, and downloading atmospheric and environmental datasets. Its key functions include:

1. **Near Real-Time Visualization** – The server generates dynamic, near real-time visual representations of incoming data, enabling users to monitor atmospheric conditions, trends, and anomalies as they develop.
2. **Archive Visualization** – Historical datasets are stored and made accessible through interactive visualization tools, allowing users to explore past trends, compare data over different time periods, and conduct retrospective analyses.
3. **Data Download** – Users can securely download datasets in various standardized formats for further analysis. The server supports filtering and customization options to allow retrieval of specific time ranges, variables, or geographic regions.
4. **Documentation and User Support** – The server hosts a comprehensive collection of guides, wikis, and technical documentation to assist users in understanding data formats, processing methodologies, and best practices for interpretation.

By integrating these capabilities, the visualization server enhances data accessibility, supports scientific collaboration, and facilitates informed decision-making for researchers, policymakers, and stakeholders.

B2: Methods for Environmental Information Acquisition

The following sections present analytical methodologies used.

B2.1 Lidar Basics

A ceilometer is a device for determining the cloud ceiling through a reflected light beam. Lidar was developed as a remote sensing technique used to precisely measure distances and properties of distant objects. The performance of a lidar system relies on how efficiently a photon can travel through the atmosphere and return to its point of origin. The returning photons are counted as a function of time, and by using the speed of light, the distance traveled by the photons can be determined. The range (distance traveled by the photons), R, can be determined by the time of flight of the photons through Equation 1:

$$R = c\frac{\Delta t}{2} \qquad \text{(Equation 1)}$$

where c is the speed of light, Δt is the time of flight, and the number 2 accounts for the round trip of photons traveled.

Light scattering and absorption enable ceilometers to conduct lidar remote sounding. By understanding the fundamentals of these processes, it is possible to extract information from the ceilometer backscatter profiles. Scattering and absorption effects fall into major categories: the elastic regime, the case for which the backscattered light is the same frequency as the outgoing laser light, and the inelastic regime in which the light experiences a frequency shift as a result of an interaction with particles or molecules in the atmosphere. Elastic scattering is the regime of scattering in which ceilometers systems operate. Ceilometers consist of the same components of many elastic backscatter lidars. These components can be organized into basic categories consisting of transmission components that include the laser and steering optics, and receiving components which include a telescope, detectors, optics, and processing stage which consists of a digitizer, software, and storage device. The transmission components in commercial ceilometers consist of pulsed laser usually emitting radiation in the near-infrared (900-1064 nm) region of the electromagnetic spectrum, with mirrors (optics) coated for optimal transmission of the laser light. To guarantee that the emitted laser light complies with eye-safety requirements the laser power is downgraded using neutral density filters or beam expanders. The beam expander is an optical device that increases the laser beam diameter while decreasing beam divergence (spread). The receiver stage consists of a telescope, optics (mirrors, filters to reduce sky/sunlight background and optics to collimate light), photodetector, and electronics to digitize and process the returning laser photons to obtain the aerosol backscatter profile.

The lidar equation for elastic backscattering (Equation 2) describes how the received signal, P, depends on atmospheric parameters and range *z*:

$$P(z) = K\frac{\beta(z)}{z^2}e^{-\int_0^z \alpha(z)dz} \qquad \text{(Equation 2)}$$

where K is the system constant, α and β are the extinction and backscatter coefficients, respectively. The extinction and backscatter coefficients consider the contributions of particles and molecules. In the formulation of the lidar equation, it is assumed that only single scattering occurs (a photon is scattered only once) and that scattering processes are independent. Independent scattering means that particles are separated adequately and undergo random motion so that the contribution to the total scattered energy by many particles (intensity) is simply the sum of the intensity scattered from each particle.

B2.2 MLH Retrieval

UCN will produce MLH retrievals for daytime mixing layers and two nocturnal retrievals for near-surface and residual layers. Aerosol backscatter retrieval methodologies perform under the assumption that the mixing layer contains relatively homogeneous concentrations of aerosols due to convective and turbulent mixing. These aerosols are capped by the clean free troposphere above the ML, creating a significant negative gradient in aerosol at this transition point, and therefore aerosol backscatter gradients. This negative gradient (i.e., top of the aerosol layer) is then attributed to the MLH (Steyn et al., 1999).

The automated MLH retrieval algorithm uses aerosol backscatter signals without the need for additional measurements. For this reason, the algorithm first addresses aerosol backscatter signal quality and applies corrections and signal smoothing (referred henceforth as corrected return signals (CRS)) 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.

Multiple Haar wavelet dilations to identify aerosol backscatter gradients and retrieve MLHs are used (Cohn and Angevine, 2000; Davis et al., 2000; Brooks, 2003; Baars et al., 2008; Compton et al., 2013). The covariance transforms (Equation 3) $w_f(a, b)$ of the Haar wavelet function $h\left(\frac{z-b}{a}\right)$ is defined as:

$$w_f(a, b) = a^{-1} \int_{CRS_{min}}^{CRS_{max}} f(z)\ h\left(\frac{z-b}{a}\right) dz, \qquad \text{(Equation 3)}$$

where (a) is the dilation factor (vertical extent) of the Haar function, (b) is the center of the Haar wavelet function, CRS_{min} and CRS_{max} are the lower and upper ranges of ceilometer signals (vertical ranges of ceilometer data), and $f(z)$ is the $\underline{CRS}$ profile as a function of altitude (z). The covariance transform is applied to $\underline{CRS}$ (Fig. 4a) from CRS_{min} to CRS_{max} with incremental dilations ($a = a_0 : a_i$; selection of values is discussed below) until the maximum dilation factor a_i is reached (Fig. 4b). The determination of the dilation factors or vertical extent of the Haar function (a) defines the number of local minimums in $w_f(a, b)$ or the covariance wavelet transform coefficient (CWTC) local minimums. Larger a values create fewer large local minimums, and lower dilation values create numerous CWTC local minimums at the heights of aerosol gradients in the measured profiles. The algorithm uses the mean of all resulting CWTC profiles ($\underline{CWTC}$) and detects local minimums in the $\underline{CWTC}$ profiles for MLH identification (Fig. 4c). The detection of the CWTC minimum is constrained to the previously defined Z_{min} height for each ceilometer and to a defined upper height limit. Additionally, a regional maximum MLH (Z_{max}) is defined based on previous studies and/or literature.

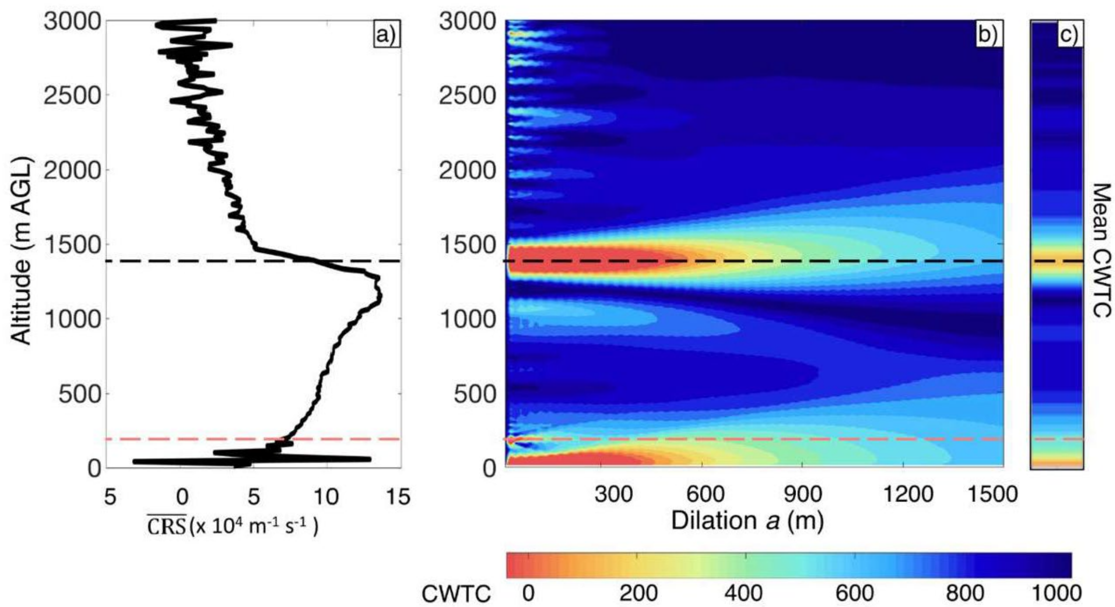

Figure 4. CHM15k $\underline{CRS}$ profile (a), corresponding covariance wavelet transform coefficients calculated with increasing dilations from a_0=15 m to a_i =1500 m (b), and the resulting mean $\underline{CWTC}$ (c).

Note that covariance wavelet transform profiles are displayed up to Z_{max} (3000 m), but Haar wavelet transform is applied to the entire $\underline{CRS}$ profile (CRS_{min} to CRS_{max}). The Red dashed line indicates Z_{min} and the black dashed line signifies the identified MLH.

The dilation factor range a_0 to a_i and height detection limits (*hl*) are defined following Stull, (1988) stages of the ML evolution using local sunrise (SR) and sunset (SS) times. Stull, (1988) defined three stages of ML evolution: stratification of the ML and formation of shallow ML, rapid ML growth, and deep convective ML periods (Figure 5). Using these stages, the algorithm performs retrievals based on defined parameters for each stage. For all of the three ML stages, the minimum dilation factor a_0 is defined as the first reported measurement height of the ceilometer ($a_0(CL51)$ = 10 m);

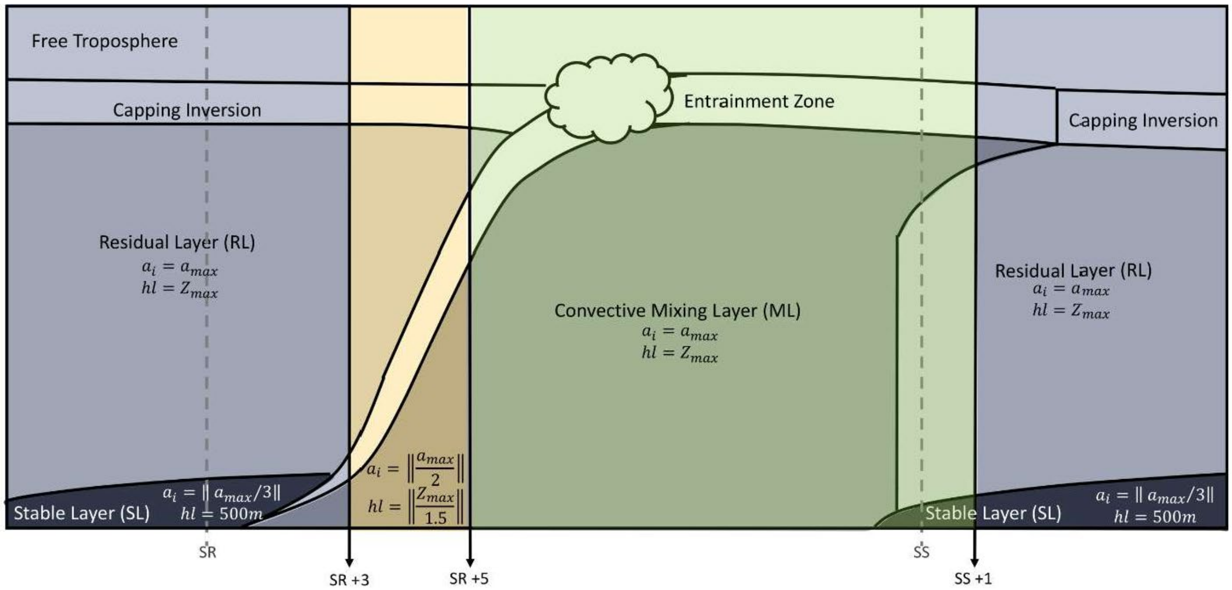

Figure 5. PBL evolution modified from Stull, 1988. Shading indicates the temporal division of settings for the Haar wavelet algorithm.

Once the Haar wavelet transforms with pre-defined parameters (Figure 5) are applied, the resulting $\underline{CWTC}$ profiles are used to identify the MLH. The algorithm stores the strongest local minimums in individual $\underline{CWTC}$ profiles and sorts them according to strength. The largest local minimum is the first guess MLH. Aerosol layering and ML stratification limit the retrieval of a single ML using aerosol backscatter profiles hence, a continuation parameter is implemented to prevent sharp changes in the retrievals as the ML depth should not change in short periods (Stull 1988). The first guess MLH is tested for continuity by comparing the height of this local minimum to the previously identified MLH. If the local minimum is not within 200 m of the previously defined MLH, the second strongest minima are tested for continuity in the same manner. If none of the four largest local minima are within the 200 m threshold, a MLH is not reported. The first retrieval for a daily file is also required to meet the continuation check using the previous day's retrievals. If no prior data is available, the first guess MLH is used.

B3: Integrity of Environmental Information

Data handling is discussed in this section, with additional details provided in Appendix A.
The designated ceilometer operator is responsible for instrument operation and maintenance, maintaining original data files, and working with the UCN to establish a data transfer method. Ceilometers produce a daily file at the end of each calendar day. On a routine basis, the ceilometer operator should ensure a daily file (00:00-23:59) is being recorded and that the size of each daily file is the same size, as a ceilometer measures on constant time and 3-dimensional space interval each day. If the size of a daily file is different in size from other daily files, it likely means a full day of measurements was not collected on that day, and the operator should note that in their logs and report it to the UCN. If this continues, the operator should check both the ceilometer and associated software for alarms and warnings, ceilometer status and operation, and the interface between the ceilometer and software. If an issue is discovered, the operator should follow the manufacturer's recommendations for appropriate corrective action. The operator should also provide notice to the UCN using the helpdesk email. At a minimum, the notice should identify the UCN ceilometer number,

suspected start date of issue, a description of the issue, and any associated alarms or warnings. A second notice should be provided to the UCN when the issue is resolved.

There are two primary methods to transfer site ceilometer files to the UCN, automated and manual. The automated transfer method differs based on ceilometer manufacturer, with the minimum requirements provided below.

B3.1 Local Access to Ceilometer Measurement Data

The automated transfer of data involves either the built in FTP data transfer method in the Lufft ceilometers, an ftp-based script on a linux server, or the installation of a custom executable on a windows-based computer attached to the ceilometer. Data may also be manually uploaded via a web-based interface. During the transfer of the data, the date of the stored files is inferred from the filename, directory structure, or whatever metadata is available. The data is then stored in a directory on the processing server that is shared with the visualization server.

B3.2 UCN Automated Data Transfer

Minimum system requirements to join UCN:

- *Vaisala/BL-View (UCN data transfer executable)*
    - Windows 10 OS (Computer provided with CL51)
    - Ability to send/receive data over at port 80/443
    - Working internet connection
    - Weblink to download executable emailed to Site Contact
    - Administrator rights or the ability to obtain one for the ceilometer computer interface

Figure 6 shows data from the CL-51 being transferred to the ceilometer's computer interface. This HIS data is then transferred via a custom executable to the processing server which converts the output into a standardized netcdf. The standardized netcdf is then processed to produce quick look images on the visualization server.

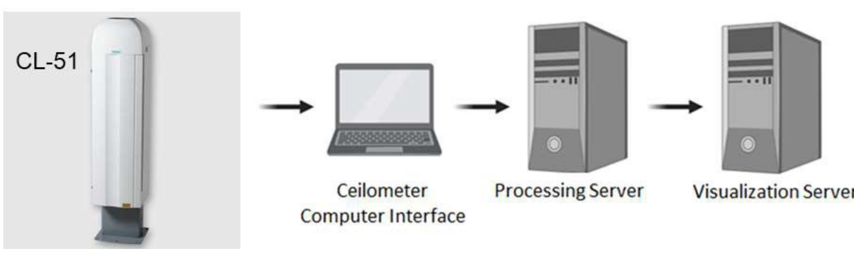

Figure 6. Typical setup for automated data transfer for Vaisala ceilometer operating with BL-View

- *Lufft (UCN data transfer script)*
    - Working internet connection
    - Admin ability to assign IP to instrument
    - UCN Data transfer script needs to be uploaded directly to instrument
    - If NO ability to assign IP, a computer with internet access can serve as data transfer interface

Figure 7 shows data from the Lufft being transferred to the processing server which will convert the output into a standardized netcdf. The standardized netcdf is then processed to produce quick look images on the visualization server.

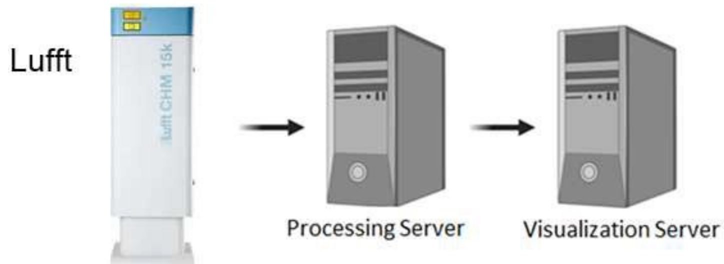

Figure 7. Typical setup for automated data transfer for Lufft ceilometer

B3.3 UCN Manual Data Upload (Vaisala and Lufft)

The ceilometer operator canconduct manual data uploads to the UCN data server. The ceilometer operator needs to know the UCN Ceilometer Identifier for their PAMS site. The UCN Ceilometer Identifier (CEILO-XX) can be found here: https://ucn.cas.hamptonu.edu/.

Once the current ceilometer number is entered, the user can select files to upload from their computer at https://ucn.cas.hamptonu.edu/uploads/. Details on how to access the data files can be obtained in each manufacturer's user manual. If the operator is uncertain as to which files to upload, please contact the data manager for the UCN via the helpdesk email.i After choosing which files to upload, the user presses the "Process Directory" button. The web page will then display the inferred year, month and day of the files, and which files will be transferred. Files where the date cannot be inferred will not be transferred. Files which have previously been transferred will, by default, not be selected but may be selected manually to be transferred again. Once the user is satisfied that the appropriate files are checked, the "Upload Checked Files" button is pressed. The status of files is updated as the process continues.

Figure 8. UCN web interface for the manual data uploads

The manual upload website provides a visual status on files uploaded, displays errors and warnings if there is a data transfer program, and provides a message for confirmation of successful data transfer to the UCN servers.

Latest Files for Ceilometer 08 (Richmond, VA)

Page loaded on: 2025-01-27 23:10:40

Ceilometer: 08 Number of Files: 10 Reload every: Never Submit

RAW Directory Files

Upload Time ▼	Directory Path	Filename
2025-01-27 18:05	/2025/1/27	CEILOMETER_1_LEVEL_2_27_L0a.his
2025-01-26 19:07	/2025/1/26	CEILOMETER_1_LEVEL_2_26_L0a.his
2025-01-25 19:06	/2025/1/25	CEILOMETER_1_LEVEL_2_25_L0a.his
2025-01-24 19:04	/2025/1/24	CEILOMETER_1_LEVEL_2_24_L0a.his
2025-01-23 19:19	/2025/1/23	CEILOMETER_1_LEVEL_2_23_L0a.his
2025-01-22 19:03	/2025/1/22	CEILOMETER_1_LEVEL_2_22_L0a.his
2025-01-21 19:04	/2025/1/21	CEILOMETER_1_LEVEL_2_21_L0a.his
2025-01-20 19:03	/2025/1/20	CEILOMETER_1_LEVEL_2_20_L0a.his
2025-01-19 19:20	/2025/1/19	CEILOMETER_1_LEVEL_2_19_L0a.his
2025-01-18 19:04	/2025/1/18	CEILOMETER_1_LEVEL_2_18_L0a.his

STAND Directory Files

Upload Time ▼	Directory Path	Filename
2025-01-27 18:05	/2025/1/27	CEILO-8_20250127000000_20250127230344_L0b.nc
2025-01-27 17:36	/2025/1/27	CEILO-8_20250127000000_20250127223336_L0b.nc
2025-01-27 17:06	/2025/1/27	CEILO-8_20250127000000_20250127220344_L0b.nc
2025-01-27 16:35	/2025/1/27	CEILO-8_20250127000000_20250127213352_L0b.nc
2025-01-27 16:04	/2025/1/27	CEILO-8_20250127000000_20250127210344_L0b.nc
2025-01-27 15:35	/2025/1/27	CEILO-8_20250127000000_20250127203336_L0b.nc
2025-01-27 15:04	/2025/1/27	CEILO-8_20250127000000_20250127200344_L0b.nc
2025-01-27 14:35	/2025/1/27	CEILO-8_20250127000000_20250127193352_L0b.nc
2025-01-27 14:05	/2025/1/27	CEILO-8_20250127000000_20250127190152_L0b.nc
2025-01-27 13:36	/2025/1/27	CEILO-8_20250127000000_20250127183456_L0b.nc

Upload Time ▼

Figure 9. UCN web interface for data transfer status

Users can view the status of their data transfer on the UCN here:
https://ucn.cas.hamptonu.edu/latest_files_for_ceilometer.php.
An example is shown above in Figure 9 for the CEILO-08 in Richmond, VA.

B4: Quality Control

Because the atmosphere being measured via aerosol backscatter is a dynamic system, there are numerous factors which impact the data quality of the retrieved aerosol backscatter from a ceilometer which propagate into the performance of any algorithm used to generate an MLH.
Major factors include:

- Low aerosol content which impacts the signal to noise ratio (SNR) of the attenuated aerosol backscatter
- Multiple aerosol gradients, especially during Planetary Boundary Layer Height (PBLH) growth and decay
- Instrument related artifacts or misidentification of precipitation or clouds as aerosol in algorithm
- Aerosol backscatter and instrument health will be monitored through available instrument diagnostics/metrics

The Data Quality Indicator goals for accuracy, precision, and completeness for this project are summarized in Table 2.

B4.1 Aerosol Backscatter

The Vaisala CL51 displays an artifact at ~40 m and therefore the minimum reliable height (Z_{min}) for the CL51 is conservatively defined at 110 m. The Lufft CHM15k photodetector can be impacted by ambient temperature changes that distort the overlap function but can be corrected using an automated technique proposed by Hervo et al. (2016) which applies a correction function to the known manufacturer's overlap correction function. The CHM15k overlap to avoid artifacts in near-surface range backscatter defines the minimum reliable height (Z_{min}), at 200 m.

The Vaisala CL31 ceilometer displays a well-documented artifact at 40-50 m in aerosol backscatter profiles when using specific firmware versions. Increasing vertical moving averages (higher averaging in higher altitudes) are applied to CL31 profiles beginning at 15 m in the lowest altitudes and increasing to 130 m at maximum ranges.

This also serves to reduce any effects from optical overlap as the CL31 full overlap is reached at approximately 70 m.

All aerosol backscatter profiles are averaged into 10-min aerosol backscatter profile bins to reduce noise and flagged for precipitation before the application of the Haar wavelet transform MLH retrieval method.

B4.2 Mixing Layer Height

The Haar wavelet transform using a range of dilations (a_0 to a_{max}) allows for the calculation of uncertainty in the retrieved MLH. Local minima for each CWTC generated from a_0 to a_{max} is saved and compared to the final retrieved ML from $\underline{CWTC}$ profiles by calculating the standard deviation of CWTC generated from a_0 to a_{max} from the $\underline{CWTC}$ MLH. This gives insight into the vertical structure of the ML and the overall performance of the algorithm. If multiple layers are present, dilations at lower ranges will create local minima at multiple layers, while larger dilation will identify the largest local minima, and therefore, large departures from the mean will be calculated. The calculation of standard deviation also serves as an additional tool to optimize Haar wavelet transform parameters. These values can be used to assess parameters used and arrive at the best parameters possible that will keep standard deviations in acceptable ranges (<200 m).

B4.3 Completeness

The UCN will use a 50% rate measurement requirement to calculate a 10-min average. Hourly averages will also be subject to a 50% rate of valid 10-min retrievals.

B5: Instruments/Equipment Calibration, Testing, Inspection, and Maintenance

Procedures for setup, testing, inspection, and schedule for preventive maintenance of the ceilometer should be consistent with the manufacturer's requirements in the ceilometer operations manual. These requirements should be provided or referenced in the PAMS Required Network Model QAPP (EPA-454/R-23-003 PAMS Required Network QAPP (R1), May 2023).

The following is provided as general guidance. When installing a ceilometer, ensure that the laser and receiver optics have a clear view of the sky, with no obstructions that interfere with the path of the light or the return signal to be received. The optimal installation is such that light path from the laser beam points vertically with a clear view of the sky above it, with no other intense light source in the field of view which could impact the receiver. In certain instances, the ceilometer can be inclined to minimize solar radiation, if found to impact the signal received, especially during high sun zenith angles. Electrical installation, including installation of a grounding wire, if necessary, should be in accordance with manufacturer recommendation.

The data acquisition system for the ceilometer can vary by vendor with some data acquisition systems contained within the ceilometer environmental enclosure and others requiring an external data acquisition system. Some ceilometers require use of additional processing software on the data logging system to collect and process the level 0 raw data files. This software may also include the ability to visualize the aerosol backscatter profiles either individually or as a time series and calculate aerosol heights layers from the backscatter data. If an external data logging system is required, it should be placed in an appropriate environmental enclosure or shelter protection. It is recommended each agency review the requirements for the ceilometer installation and setup prior to procurement to ensure the ceilometer meets their specific needs or available configuration.

B5.1 Operation and Maintenance

Once setup and operating, a ceilometer requires periodic checks of the optical window, automated alarms or warnings, and data acquisition. Users should check the instrument and the associated operating software for data messages routinely related to alarms and warnings. These checks will be dependent on the configuration of the ceilometer and the associated data acquisition system used. Users should refer to the manufacturer's operating manual and develop a routine checklist specific to the ceilometer to check for warnings and alarms.
Ceilometer data quality is directly related to both the cleanliness and clarity of the optical window, laser performance, and the alignment and level of the instrument. A site operator should check the optical window on a routine basis. If the optical window becomes cracked, shows signs of degraded clarity, or a broken seal the manufacturer should be consulted for an appropriate remedy. Consult the manufacturer's operating manual for specific instructions on additional equipment maintenance including optical window cleaning.
Once the ceilometer is set to data collection mode, it is important to carefully examine the data record over a period of several days by comparing the mixing height estimates to the backscatter intensity data. Such a comparison is discussed in the Appendix A.

B5.2 System Calibration

Each manufacturer provides a calibration certificate when the unit is shipped new. The ceilometer is not designed to undergo a field or laboratory calibration on a routine basis. If the ceilometer experiences failure of a major component, it may require a new calibration by the manufacturer and the site operator should consult with the manufacturer.

The ceilometer aerosol backscatter signal is based on photon counts and any processing of the signal (e.g., to calculate cloud height) involves an algorithm that searches for relative changes (i.e., gradients) within the profile. While ceilometer data can be used for more quantitative uses, such as day-to-day inter-comparison of aerosol loads (e.g., aerosol optical thickness), the use of a ceilometer for MLH determinations does not require an absolute calibration. Vendor provided software continuously monitors instrument status, so any data collected under faulty hardware conditions will be flagged via UCN processing and, if necessary, removed prior to processing to UCN Level 2 data posting.

The best assessment of the instrument performance on a continuous basis is a qualitative assessment of the derived data products through visual plots, local user knowledge of expected meteorological conditions and expected ranges in MLH/PBLH. Such an assessment can quickly identify functional issues with the ceilometer, which would most likely be visible in unusual variations in the aerosol backscatter profile plots.

B6: Inspection/Acceptance of Supplies and Services

The primary criteria for UCN data acceptance is the completeness of the ceilometer data processing performed by HU. The state or local agency is responsible for providing their ceilometer data to the UCN. The UCN will generate a quarterly report on data files received and processed and post the reports on the site for review and acceptance by the EPA and the relevant state or local agency.

B7: Environmental Information Management

B7.1: Information Handling and Storage

After data have been transferred and processed for a site the validated dataset will be available at the UCN website: https://ucn.cas.hamptonu.edu/latest_files_for_ceilometer.php. See section D1 for additional information.

B7.2: Information Security

As discussed in section B3.2, the UCN manual upload website provides a visual status on files uploaded. Users will receive an error message if there is a problem or a confirmation for successful data transfer to the UCN servers. A color-coded system has been implemented to inform data providers the status of data from their site; see Figure 10 Green – data is within one day, Yellow – data is less than a week behind, White – partial data is available from the site and is more than a week behind, Red – no data has been received.

Ceilometer	Site Name	RAW First Date	RAW Last Date	STAND First Date	STAND Last Date
CEILO-01	Unknown	2021-10-09	2022-02-28	2021-06-09	2022-02-18
CEILO-04	Unknown	2022-05-24	2022-06-09	2088-05-24	2088-06-09
CEILO-05	Unknown	2021-10-19	2024-07-30	2021-10-19	2024-07-30
CEILO-07	Philadelphia, PA	2021-12-04	2022-01-30	2021-12-04	2022-01-30
CEILO-08	Richmond, VA	2021-10-19	2024-08-03	2021-10-19	2024-08-03
CEILO-09	Washington D.C.	2021-10-18	2024-08-03	2021-10-18	2024-08-03
CEILO-1	Unknown	2023-07-01	2023-07-03	2020-11-01	2020-11-03
CEILO-10	Las Vegas, NV	2021-11-14	2022-01-26	2021-11-14	2022-01-26
CEILO-11	Indianapolis, IN	2018-03-01	2024-08-03	2018-03-01	2024-08-03
CEILO-12	Providence, RI	2018-08-17	2023-10-19	2018-08-17	2023-10-19
CEILO-13	Manhattan, KS	2019-10-28	2020-01-28	2019-10-28	2020-01-28
CEILO-14	Salt Lake City, UT	2021-04-16	2022-08-17	2021-04-16	2022-08-17
CEILO-15	Londonderry, NH	2020-01-01	2024-08-03	2020-01-01	2024-08-03
CEILO-17	Utah Technical Center	2017-11-02	2024-08-03	2017-11-02	2024-08-03
CEILO-2	Unknown	2023-07-01	2023-07-08	2020-11-01	2020-11-08
CEILO-23	Ardenstville, PA	2020-03-25	2024-08-03	2020-03-25	2024-08-03
CEILO-25	Superior, CO	2017-10-25	2024-08-03	2017-10-25	2024-08-03
CEILO-27	Essex, MD	2021-09-09	2024-07-19	2021-09-09	2024-07-19
CEILO-28	St. Maries, ID	2020-08-13	2024-08-03	2020-08-13	2024-08-03
CEILO-29	Tacoma, WA	2020-08-04	2024-08-03	2020-08-04	2024-08-03
CEILO-30	Seattle, WA	2020-11-04	2024-06-02	2020-11-04	2024-05-29
CEILO-31	Cincinnati, OH	2020-07-15	2024-08-03	2020-07-15	2024-08-03
CEILO-33	Duke Forest,NC	2022-03-23	2024-08-03	2022-03-23	2024-08-03
CEILO-34	Blaine, MN	2020-12-16	2023-09-12	2020-12-16	2023-09-12
CEILO-36	Raleigh, NC	2021-04-13	2023-08-30	2021-04-13	2023-08-30
CEILO-37	Northbrook, IL	2022-02-26	2024-08-03	2022-02-26	2024-08-03

Figure10. UCN web interface for data transfer status

In addition, for technical support, the UCN has installed the RT (Request Tracker) system. Request tickets are generated by sending an email to ucn_help@cas.hamptonu.edu. Communication with the ticket system is handled via email. Users who wish to interact with the ticket system via a web-based interface may request to have an account set up, allowing login and view of ticket progress at rt.cas.hamptonu.edu.

B7.3: Information Systems

Table 8 identifies the types of hardware, operating systems (OS), and specialty software that will be used for this project, including any specialized requirements requiring the use of anything other than the standard EPA-issued laptop with Microsoft Windows OS using Microsoft Office Tools.

Table 8. Required Hardware, Operating System, and Types of Specialized Software for EIO

Hardware	Operating System	Non-Microsoft Office Software and Version/ Special Performance Requirements/Use
☒ **Standard EPA Issued Laptop**	Microsoft Windows 11	There are no special hardware, software, and performance requirements anticipated for this project.
☐ **Standard EPA Issued Laptop**	Microsoft Windows 11	

Hardware	Operating System	Non-Microsoft Office Software and Version/ Special Performance Requirements/Use
☐ **EPA Issued High Computing Laptop**	Microsoft Windows 11	
☐ **Non-EPA Laptop/ Personal Computer (Model):**	Microsoft Windows 11	There are no special hardware, software, and performance requirements anticipated for this project.
☐ **Non-EPA Issued Laptop/Personal Computer (Model):**	☐ Microsoft Windows (No): ☐ Apple (No): ☐ Linux (No): ☐ Other (No):	
☒ **Other Hardware (Type/Model):** Ceilometer with data logging capabilities. Computer maybe internal or external to the ceilometer depending on manufacturer.	Microsoft Windows 10	UCN Data transfer script Haar Wavelet processing code with internally designed QC checks.

B7.4: Information Accessibility

Data that belong to the Federal government are subject to the Federal Information Security Modernization Act (FISMA). Research data associated with any scientific product, as appropriate, will be shared publicly after clearance and acceptance of the product by a journal, either through Science Hub or another data repository. The metadata of the publicly available data will be recorded in Science Hub which transmits this information to data.gov.

C: Assessments and Response Actions and Oversight

C1: Assessment and Response Actions

C1.1: Assessments

For QA Category B projects, QA audits are conducted at the discretion of management and/or the QAM. If a QA Audit is conducted, it will be in accordance with ORD QA Policy titled, Audits of Technical and Quality Systems (PPM 13.13). Any findings, observations, noteworthy best practices, or recommendations for improvement will be compiled in a report and filed with the project records. Draft publications and products resulting from this project will undergo ORD clearance in RAPID/STICS and a QA Review documented in QA Track prior to dissemination as required by both ORD Policies titled, ORD Clearance Policy and Procedures (PPM 14.03) and QA Review of Scientific and Technical Work Products (PPM 13.11). All ORD draft publications and products are reviewed at a minimum by ORD 1st and 2nd line supervisor for clearance and documented within the STICS system. All products will adhere to the Agency Peer Review Handbook, and ORD Policies for Internal Technical Reviews. The TL will maintain a copy of all Internal Technical Reviews as well as Peer Review Documentation within their Project file and upload any necessary peer review documentation with their product clearance record, as per ORD and their Center Policy for RAPID/STICS clearance.

C1.2: Response Actions

The TL is responsible for ensuring that non-audit related findings and non-conformances are documented, and that subsequent response or corrective actions are carried out and documented. The TL is responsible for response actions associated with findings within an audit report. The QAM will track the implementation status of corrective actions from audit findings and verify the implementation of corrective actions occurred. Any corrective actions and responses will be documented and filed with the Assessment Report and stored by the TL as part of the project's study file. Any Corrective Actions and Response Actions associated with product reviews within STICS will be documented and tracked within the ORD clearance system. All comments from Internal Technical Reviews are taken into consideration, documented in the project file's peer review record, and included in Clearance. For non-influential work products (those categorized as "other"), external peer review comments are addressed, reconciled, and a response to peer reviewer's comments is prepared, included in Clearance, and added to the peer review record in the project file. For products that are not considered "influential", the Agency may disclose the peer review report and Agency's response to the report (if prepared). Products are revised in response to the peer review.

C2: Oversight and Reports to Management

In addition to current tracking on data uploads, quarterly reports for each UCN site will be generated on data completeness metrics. These metrics will include percent data uploaded to the UCN from each site and percent data processed via UCN. These reports will be made available on the UCN website and presented at the PAMS Required Site Workgroup meetings led by OAQPS.

UCN meetings will be conducted with key personnel at a minimum of monthly. The frequency of meetings may be adjusted as the project progresses and need for the meeting increases or decreases. There may also be times when smaller meetings may be needed to discuss more focused areas of research.

D: Environmental Information Review and Usability Determination

D1: Environmental Information Review

The following subsections describe UCN data processing, quality assurance checks, sampling calculations as well as data management procedures.

Data received from SLTs will first undergo standardization procedures. All incoming data will be standardized in its native resolution (temporal and vertical) and contain the variables and attributes in Tables 9 and 10. Any data gaps will be completed with empty bins to maintain the expected standardized dimensions. Any reoccurring data outages are automatically detected. HU will notify SLTs via email if any action is needed.

UCN will facilitate data download through the UCN data portal. Incoming data files in native commercial format denoted at L0a files are reformatted to a standardized UCN format denoted as L0b files. Daily (24-hour) data files in standardized UCN format (Tables 9 and 10) will be available for download at the UCN data portal and are denoted as L1 files.

Table 9. Global Attributes in UCN L1 standardized file

Global Attribute Name	Description	Example
ALG_instrument_code	UCN Internal Instrument code	CEILO-XX
ALG_site_code	UCN Internal Site code	ABCD
organization	SLT Organization	ABCD Department of Environment
project	Project Name	EPA_PAMS
aqs	AQS Code	SS-CCC-MMMM
epa_region	EPA Region Number	1
site_name	Site Name (if applicable)	Abcd Abcd
location_city_state	Cite and State of site	Abcs, AB
structure_height_m_agl	Structure height of installed ceilometer (if any)	X
site_elevation_m_asl	Site elevation (meters above sea level)	X.X
instrument_make	Ceilometer Instrument Maker	Vaisala
instrument_model	Ceilometer model	CL51
firmware_version	Ceilometer firmware version	X.X
software	Ceilometer software name and version	BL-View 2.1.1
vertical_resolution_m	Aerosol backscatter vertical resolution	10
vertical_range_m	Aerosol backscatter maximum range	15,400
temporal_resolution_s	Aerosol backscatter temporal resolution	16
missing_values	Missing value code	NaN
site_contact	SLT contact	aaa_bbbb@abcd.gov
DM_contact	Data Manager Contact (UCN)	John McNabb JOHN.MCNABB@HAMPTONU.EDU
Notes	Notes regarding data file	Level 0 – Standardized raw data

Note that the standardized format was defined to account for varying ceilometer models and makes, therefore the variables listed in Table 10 may not apply to all ceilometer models.

Table 10. Variables in UCN L1 standardized file

Variable Name	Units	Long Name / Description
time_UTC	UTC epoch time	seconds since January 1, 1970 00:00:00
elevation_m	m	elevation ASL
latitude_deg	Degrees	Degrees north
longitude_deg	Degree	Degrees east
azimuth_deg	degrees	degrees from N
zenith_deg	degrees	degrees from vertical
altitude_asl_m	m	Altitude above sea level (ASL)
wavelength_nm	nm	instrument wavelength
laser_state_per	percent	state of laser %
detector_state_per	percent	state of detector %
optics_state_per	percent	state of optics %
internal_temp_K	degrees K	internal temperature
external_temp_K	degrees K	external temperature
detector_temp_K	degrees K	detector temperature
laser_temp_K	degrees K	Laser temperature
laser_pulses	number of laser pulses per record (lp)	number of laser pulses per record (lp)
scale	n/a	scaling factor
background	millivolts	background in millivolts
bsc_prof	km^-1.sr^-1	attenuated backscatter
commercial_pbl_m	m	commercial PBL height
cbh_m	m	commercial cloud base height
quality_flag	n/a	Quality code following Table 9

D1.1 Verification and Validation Methods

As reported in Caicedo et al., 2020, MLH standard deviations are used to further verify retrievals by excluding retrievals with standard deviations above 200 m. MLH retrievals identified at times when precipitation was identified are automatically removed. Cloud signals can create difficulty for the Haar wavelet algorithm as these signals tend to either attenuate aerosol backscatter above the cloud layer or create enhanced signals immediately below the cloud base. If a cloud-base height (CBH) is identified within 300 m of the identified MLH, the MLH is removed. Note that under a cloud-topped ML, the MLH = CBH, and therefore only a CBH is reported. The final retrievals are reported with a standard deviation after all the above quality checks in the UCN data processing software are performed to arrive at the most robust and automated outputs. In addition to ML retrievals with reported standard deviations, aerosol backscatter profiles used in conjunction with retrievals provide further context needed to understand ML vertical structure and aerosol layering.

Table 11 below details the flagging convention used for this project.

Table 11. AQS Null Data Codes

Qualifier Code	Qualifier Description	Qualifier Type Description	Qualifier Type	Comments:
AM	Miscellaneous Void	Null Data Qualifier	NULL	
AN	Machine Malfunction	Null Data Qualifier	NULL	Communication error: instrument not collecting, data set to null [NA]
AT	Calibration	Null Data Qualifier	NULL	
BA	Maintenance/Routine Repairs	Null Data Qualifier	NULL	
QX	Does not meet QC criteria	Null Data Qualifier	NULL	

D2: Usability Determination

D2.1 Process for Determining Usability of Environmental Information

The usability of environmental information derived from the automated planetary boundary layer height (PBLH) retrieval algorithm is determined through a multi-step evaluation process that includes data validation, uncertainty assessment, and confidence scoring. First, the retrieved PBLH data undergo preprocessing and quality control checks, where noise filtering, signal smoothing, and background subtraction are applied to ensure data integrity. Next, the algorithm's retrievals are validated against independent reference datasets, such as radiosonde profiles, ceilometers, and Doppler lidar measurements, using statistical performance metrics like bias, root mean square error (RMSE), and correlation coefficients (R^2).
Following validation, the algorithm assigns a confidence score to each retrieval based on three primary criteria: (1) agreement between different retrieval methods (gradient, wavelet, and variance-based approaches), (2) signal-to-noise ratio (SNR) of lidar backscatter data, and (3) temporal stability of the retrieved PBLH. High-confidence retrievals, which exhibit strong agreement and minimal uncertainty, are deemed fully usable for regulatory and research applications. Moderate-confidence retrievals, where minor discrepancies exist, may require additional validation through averaging or comparative analysis before use in air quality modeling. Retrievals flagged as low confidence due to cloud contamination, weak signals, or excessive noise are deemed unusable for regulatory assessments and excluded from decision-making datasets.

Documentation of Usability Determination

The determination of environmental information usability will be systematically documented through a data quality assessment report integrated into project records. Each retrieval will be assigned a usability classification (e.g., high-confidence, moderate-confidence, low-confidence) that will be recorded in metadata files accompanying the dataset.

Additionally, summary statistics of retrieval accuracy, including bias and RMSE calculations, will be compiled into periodic validation reports that compare the lidar-derived PBLH estimates to radiosonde and ceilometer observations. These reports will be submitted to the EPA and relevant stakeholders, ensuring transparency in data usability assessments. A centralized database or data management system will store both raw and processed retrievals, along with associated confidence scores, to facilitate long-term tracking of algorithm performance and usability trends.

D2.2 Communication of Limitations on Environmental Information Use

To ensure proper interpretation and application of the lidar-derived PBLH data, limitations on data usability will be clearly communicated to end users through data documentation, standard operating procedures (SOPs), and metadata descriptions. Key limitations—such as retrieval uncertainty in stable boundary layers, potential errors in low-aerosol environments, and cloud contamination impacts—will be explicitly stated in dataset metadata and QA reports.

For regulatory and research applications, guidelines on data use will be provided, outlining conditions under which PBLH retrievals are reliable and when additional validation steps are necessary. In cases where data quality does not meet the required standards for air quality modeling or emissions control planning, these datasets will be flagged as unusable and excluded from decision-making processes. Stakeholders, including EPA program managers and atmospheric scientists, will be informed of these limitations through technical reports, presentations, and training sessions to ensure informed decision-making.

By implementing transparent documentation, rigorous quality assessment, and clear communication protocols, the algorithm ensures that only reliable environmental information is utilized in regulatory assessments and atmospheric research.

E. References

Caicedo, V., Delgado, R., Sakai, R., Knepp, T., Williams, D., Cavender, K., Lefer, B., Szykman, J. An automated common algorithm for planetary boundary layer retrievals using aerosol lidars in support of the U.S. EPA Photochemical Assessment Monitoring Stations Program, J. Atmos. Oceanic Technol., doi.org: 10.1175/JTECH-D-20-0050.1, 2020.

Hervo, M., Poltera, Y., and Haefele, A.: An empirical method to correct for temperature-dependent variations in the overlap function of CHM15k ceilometers, Atmos. Meas. Tech., 9, 2947–2959, doi:10.5194/amt-9-2947-2016, 2016.

Kotthaus, S., O'Connor, E., Münkel, C., Charlton-Perez, C., Haeffelin, M., Gabey, A. M., and Grimmond, C. S. B.: Recommendations for processing atmospheric attenuated backscatter profiles from Vaisala CL31 ceilometers, Atmos. Meas. Tech., 9, 3769–3791, doi:10.5194/amt-9-3769-2016, 2016.

Stull, R. B.: An Introduction to Boundary Layer Meteorology, Kluwer Academic, 1988.

Appendix A: Interpreting Ceilometer Data

a. Planetary Boundary Layer

Ceilometers are powerful tools for visualizing aerosol distribution, cloud-top altitudes, and pollution transport in the PBL. Ceilometer data is typically depicted with time series using logarithmic color scales to account for the large range of aerosol backscatter measurements. Figure A-1 is a time series plot of data from a ceilometer with altitude in kilometers on the y-axis and time in Universal Coordinated Time (UTC; EST = UTC-5) on the x-axis. The images are color-coded, with reds and yellows corresponding to high concentrations of scatters from large and moist particulates (i.e. cloud drops, drizzle, rain, etc.), and blue for low values of aerosol backscatter. Changes in aerosol backscatter in the vertical denote aerosol layering.

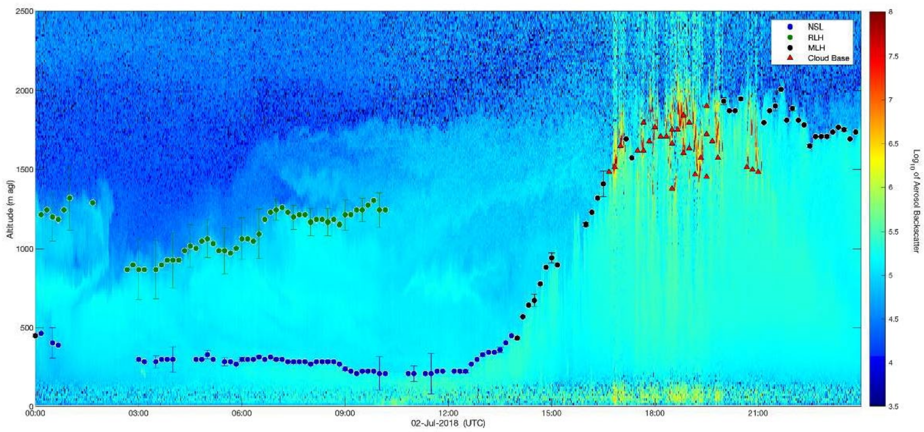

Figure A-1. Planetary boundary layer ceilometer (Vaisala CL51) aerosol backscatter retrievals.

The blue markers represent the height of the NSBL, black markers the ML, and green markers the RL. Red markers denote cloud base.

Figure A-1 shows the typical evolution of the PBL during the morning, afternoon, and early evening. Overnight, in the absence of sunlight, the PBL shrinks to a narrow layer next to the Earth's surface, called the Nocturnal Stable Boundary Layer (NSBL, visible from 00:00 UTC until approximately 13:00 UTC in Figure A-1). After sunrise, the surface begins to warm, and Mixed Layer (ML) growth begins eventually surpassing the NSBL and reaching the height of the Residual Layer (RL) aloft approximately from ~13:00 to 17:00 UTC in Figure A-1. Most of the particulate matter in the PBL is concentrated near the surface, as indicated by the yellow colors in Figure A-1.

b. Precipitation

Figure A-2 shows the presence of clouds and precipitation in a time series plot of data. The red thin horizontal lines in heights between 1000-7000 meters are due to the presence of clouds. After 5:00 UTC rain is observed and lasting approximately 5.5 hours. The rainfall is discernible from the yellow to red vertical signals extending from the cloud bottom (red horizontal lines) towards the surface. The vertical yellow stripes beginning in higher altitudes and weakens with decreasing height (~12:00 and 22:30 UTC) its signal impacted by increased return signals from solar radiation and by the presence of clouds in the atmosphere.

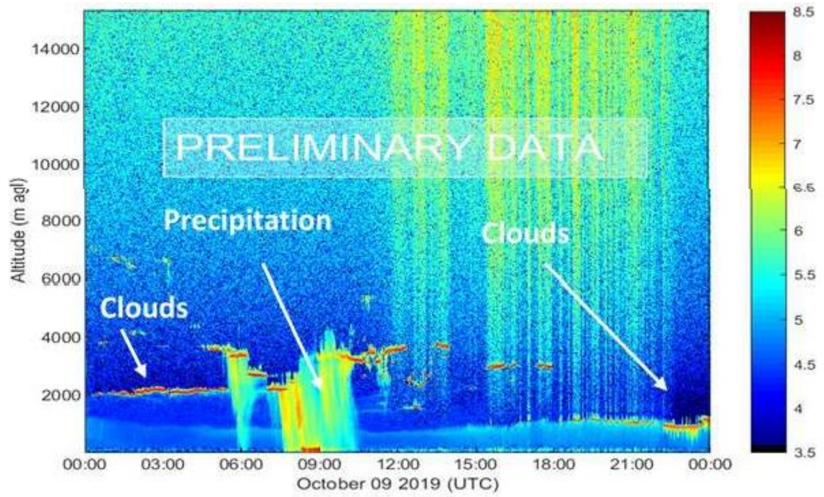

Figure A-2. Ceilometer aerosol backscatter retrievals showing the presence of clouds and precipitation.

c. Smoke

A recent smoke transport case was documented using ceilometer sites. From approximately July 8 – July 20, 2019, smoke from Canadian fires was seen in Satellite images over ceilometer sites (Figure A-3 left panel). Figure A-3 shows aerosol backscatter at two ceilometer sites in New York (top right) and Maryland (bottom right) from July 8, 2019 – July 10, 2019. The aerosol backscatter images show a more complex lower troposphere (0-5000 meters) than the earlier images shown (Figures A-1, A-2). Both aerosol backscatter plots (right panel) begin on July 8, 2019 with the presence of clouds and rain during nighttime through about 16:00 UTC in New York (top right) and 18:00 UTC in Maryland (bottom right). Higher aerosol backscatter within the daytime PBL (~10:00 UTC to 00:00 UTC) is occasionally capped with clouds (red aerosol backscatter intensities) at heights between 1500-2000 meters. Above the PBL (i.e., heights greater than 2500 meters), enhanced aerosol backscatter is observed and indicative of the advection of smoke at both locations. A denser layer aloft can be observed in the New York and Maryland aerosol backscatter profiles and confirmed in the VIIRS “True Color” satellite image (left panel). Ceilometers serve to track aerosol transport and monitoring any impacts above or within the PBL. In the case of Figure A-3, the smoke transport was not injected into the PBL and therefore did not affect surface air pollution.

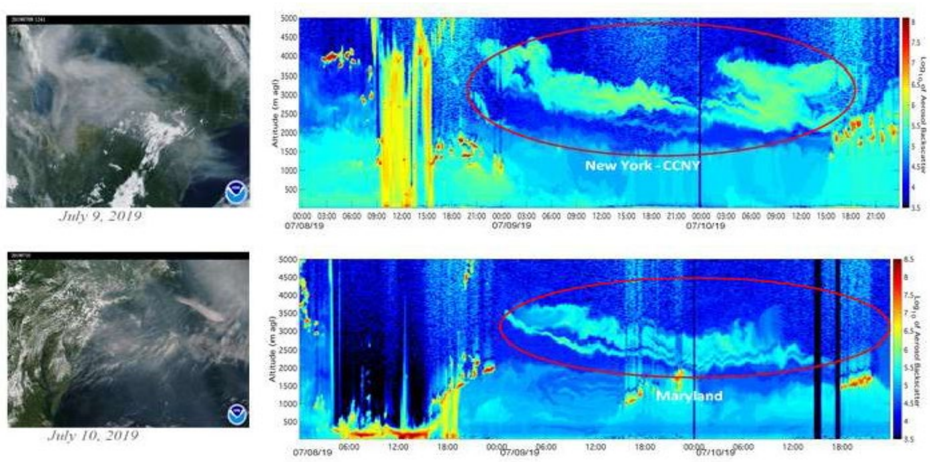

Figure A-3. Satellite and aerosol backscatter images for July 8-10, 2020.

Satellites "true color" images" from the Visible Infrared Imaging Radiometer Suite (VIIRS) for New York (top left) and Mid-Atlantic states (bottom left), and ceilometer aerosol backscatter time series taken at the City College of New York and Howard University-Beltsville Research Site in Maryland. Satellite images courtesy of NOAA AerosolWatch[2].

d. Instrument Interference

Ceilometer signals and artifacts must be accounted for the correct interpretation of aerosol backscatter measurements and before the application of processing algorithms. For instance, the incomplete lidar signals due to optical overlap can limit ceilometer retrievals in regions below the full overlap greatly impacts near surface ranges (Figure A-4a). Adequate corrections for the regions are important for near-surface aerosol layer detection for instruments with increasing range of complete overlap (Figure A-4b). Tools such as that described by Hervo et al. (2016) [3] applies a correction function to the known manufacturer's overlap correction function in order to account for the temperature dependence of the overlap function.

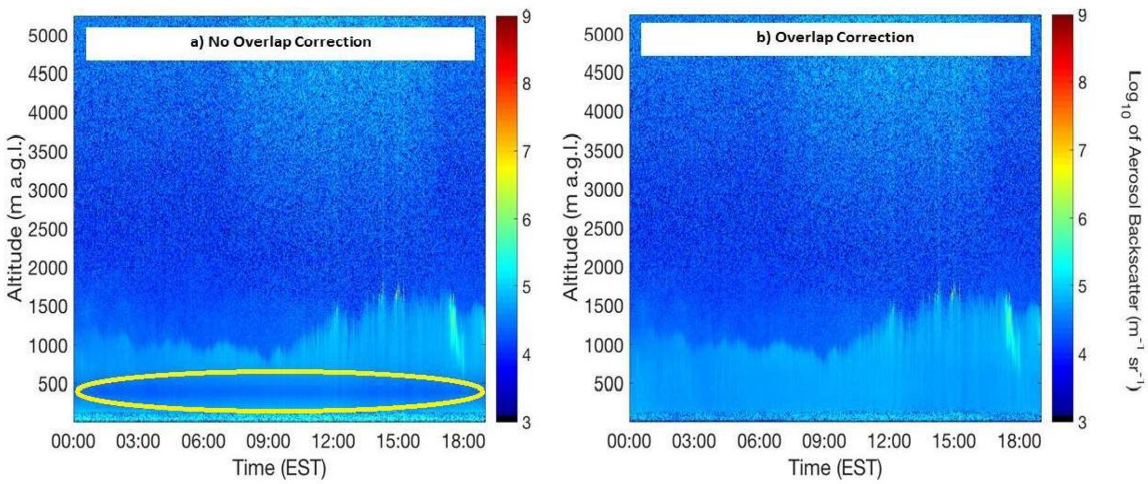

Figure A-4. Ceilometer aerosol backscatter time series for signals without an overlap correction (a) and with overlap correction (b).

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[2] NOAA AerosolWatch: https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/

[3] Hervo et al.; An empirical method to correct for temperature-dependent variations in the overlap function of CHM15k ceilometers, Atmos. Meas. Tech., 9, 2947–2959, 2016.