Unified Ceilometer Network:
Aerosol Profiling and Planetary Boundary Layer Retrievals in Support of PAMS

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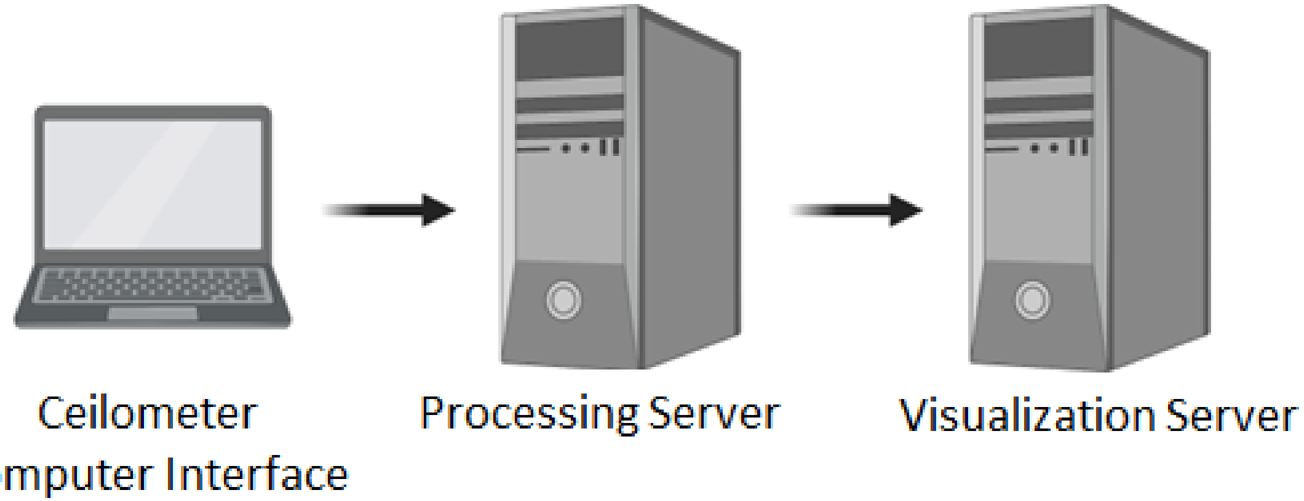
[7]Maryland Department of the Environment
[8]U.S. Environmental Protection Agency



Minimum system requirements to join UCN:

- Windows 10 OS
- Ability to send/receive data over at port 80/443
- Working internet connection
- Administrator rights or the ability to obtain one for the ceilometer computer interface

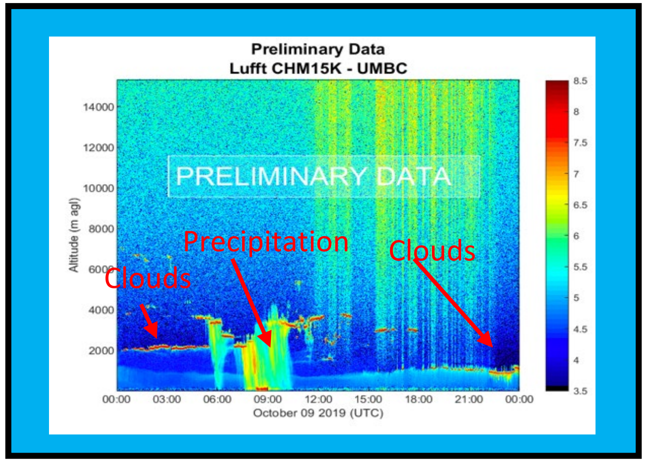
Integrated 3D Air Quality System

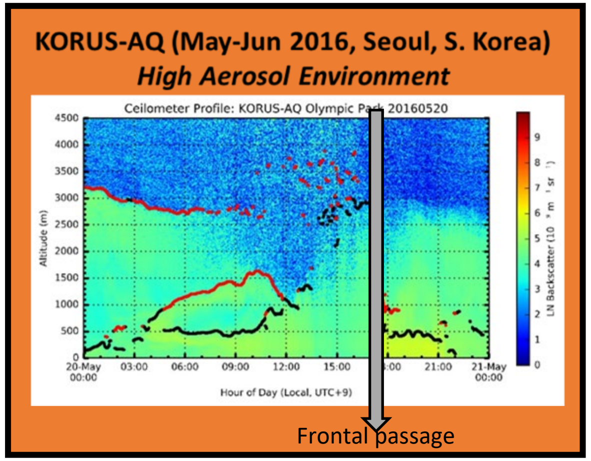
Aerosol Backscatter

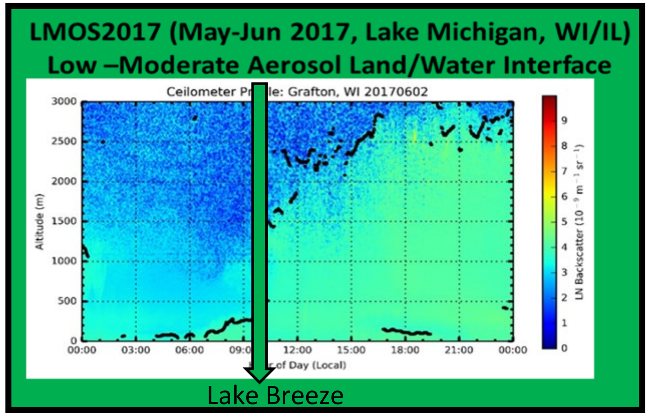
- Improve Remote Sensing O_3 retrievals: reduce uncertainty
- Optical/Physical Properties from Multiwavelength Elastic Lidar Retrievals
  - Polarization, Color Ratio, Angstrom Exponent
- PBL Height Temporal Evolution
- Validation of Models and Satellite Products
  - Column vs Surface (Below and Above PBL contribution)
- Volcanic Ash
  - Air Traffic $\rightarrow$ $$$
- Fire Weather
  - Smoke Intrusion $\rightarrow$ AQ/Public Health Alert and Exceedance Justification

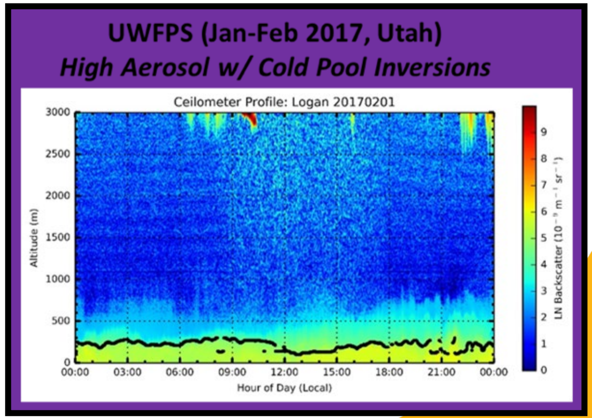
Planetary Boundary Layer (PBL) Monitoring

- Understanding the evolution of the **PBL** is crucial for air pollution as PBL dynamics control pollutant accumulation and dispersion, which in turn also influence aerosol-radiation PBL interactions
- Current observations are rarely available in the spatiotemporal scales needed to further our understanding of complex PBL dynamics.
- Ceilometers (Aerosol Backscatter) can monitor:
  - Clouds and precipitation
  - PBL stratification: residual layers, nocturnal boundary layers (NBL), lofted aerosol layers, etc.
  - Synoptic changes influencing PBL dynamics
  - Impact of local circulation (bay/sea/lake/land breeze)
  - Strong shallow inversions







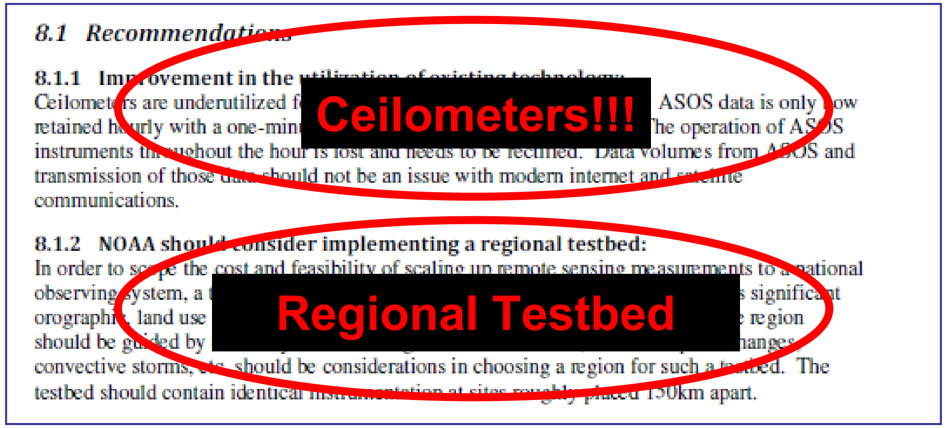


Observations Lead The Way

NRC
Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks (2009)

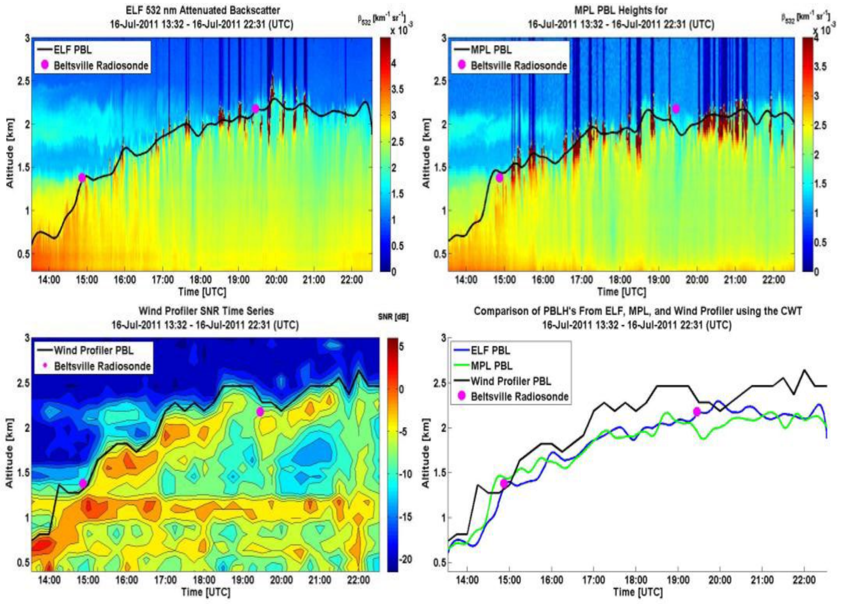
NSF
Thermodynamic Profiling Technology Workshop (2011)

NASEM
The Future of Atmospheric Boundary Layer Observing, Understanding, and Modeling (2018)


8.1 Recommendations

8.1.1 Improvement in the utilization of existing technology:
Ceilometers are underutilized f… ASOS data is only now retained hourly with a one-minu… The operation of ASOS instruments throughout the hour is lost and needs to be rectified. Data volumes from ASOS and transmission of those data should not be an issue with modern internet and satellite communications.

8.1.2 NOAA should consider implementing a regional testbed:
In order to scope the cost and feasibility of scaling up remote sensing measurements to a national observing system, a t… s significant orographic, land use … region should be guided by … changes, convective storms, etc. should be considerations in choosing a region for such a testbed. The testbed should contain identical instrumentation at sites roughly placed 150km apart.



Compton et al. (2013), J. Atmos. Ocean. Tech., doi:10.1175/JTECHD-12-00116.1

PAMS Program Programmatic Need

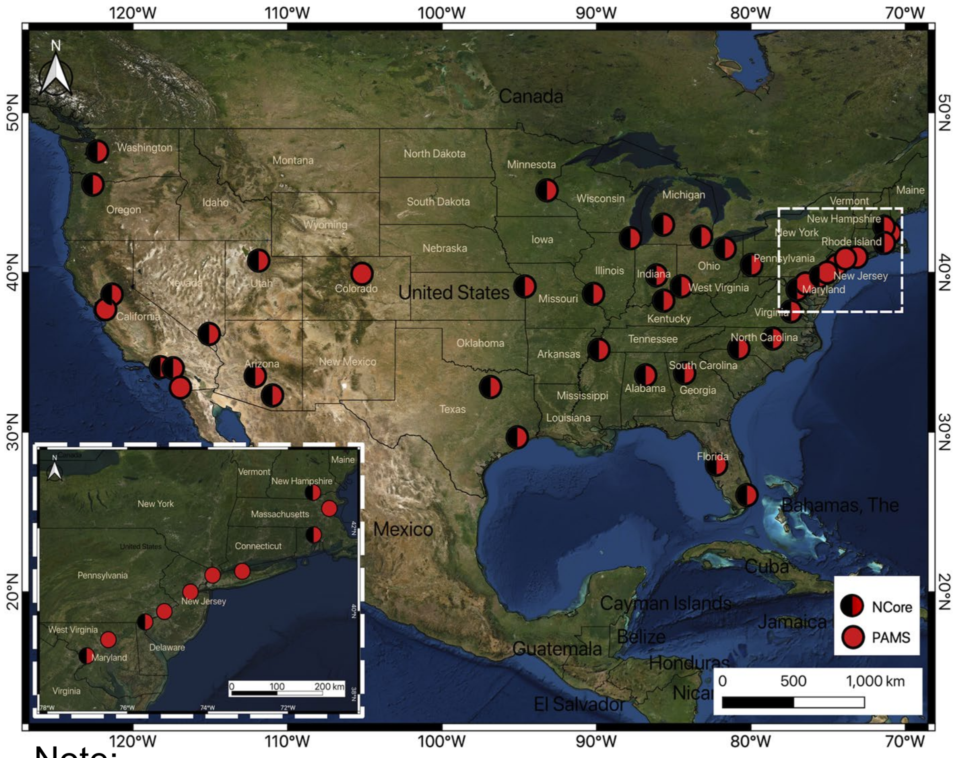
PAMS Mixing Layer Height (MLH) requirement

- PAMS redesign added new requirement for State and Local air quality agencies to **measure hourly MLH** at the national PAMS.
  - Primarily driven by model evaluation data needs.
- Ceilometers provide a low-cost option to meet MLH requirement.

Issues:

- Performance of current algorithms (research and commercial) not well document across commercially available ceilometers.
- Common MLH algorithm consistently implemented across a heterogeneous network avoids inconsistencies in data products and increases confidence in use of data for model evaluation.
- Develop centralized standardization of data outputs and retrievals.

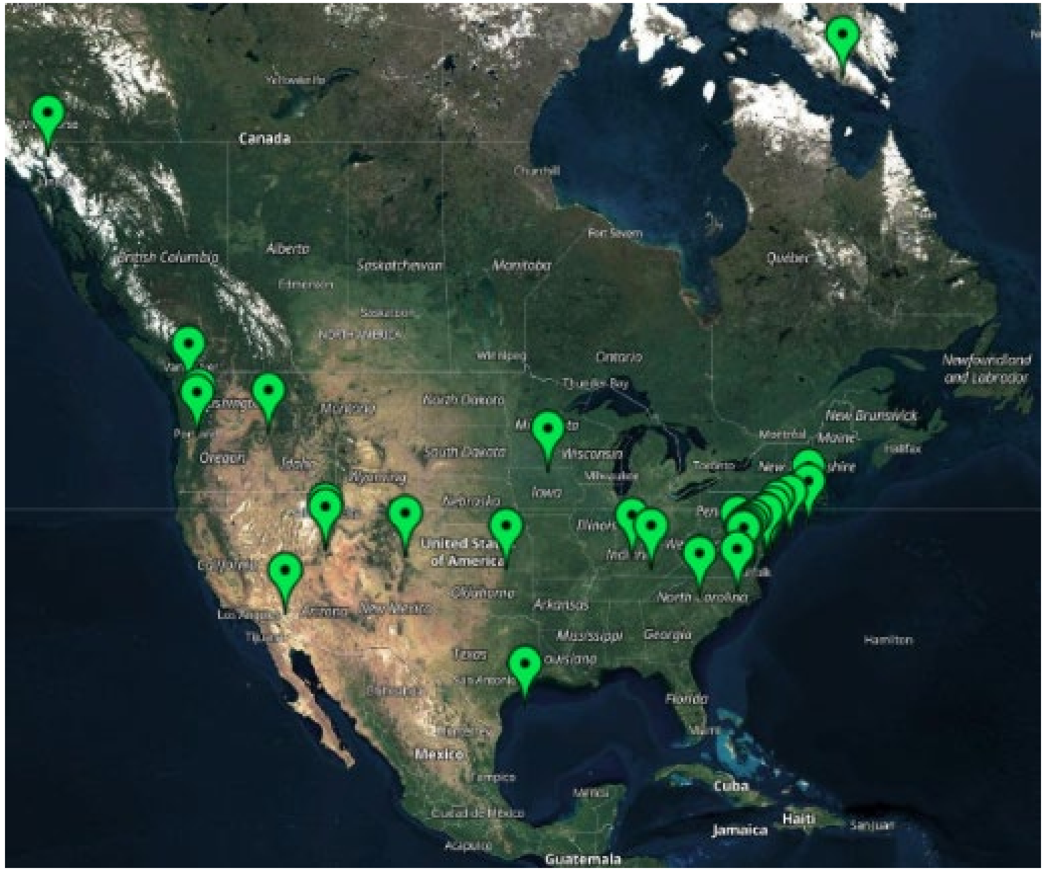
EPA PAMS/NCORE Sites



Note:

- MLH term used to describe the day-time convective boundary layer.
- Ceilometer can measure day and night; we use Planetary Boundary Layer Height (PBLH) instead of MLH as we are using ceilometer measurements to characterize boundary layer through the entire day.

Unified Ceilometer Network (UCN)



https://ucn-portal.org

- UCN began with evaluation studies (Ad-Hoc Ceilometer Evaluation Study) and prototype networks (E-PAMS Network Testbed) since December 2016.
- U.S. EPA mandate to state and local air quality agencies to measure hourly MLH at the national PAMS:

  State Implementation Plan (SIP) modeling data needs

- Collaboration between 32 states and 5 federal agencies (EPA, NASA, NOAA, ARMY, USDA), 8 academic institutions and 1 international agency (Environment and Climate Change Canada) for extensive observational coverage in North America (58 sites).
- UCN hosts, process, display, and distribute ceilometer data and products.
- Open Source

Ad-hoc Ceilometer Evaluation Study

- Joint Effort:
  - MDE/EPA/UMBC
  - Federal: NASA/NOAA
  - Academia: CCNY/Hampton and Howard University
- Measurements to help guide EPA PAMS program implementation for new hourly MLH requirement.
- Evaluation of Aerosol Backscatter and mixing layer height retrievals from commercial ceilometer/lidars (**software**):
  - **Campbell Scientific** CS135 and SkyVue Pro (**Viewpoint**)
  - **Leosphere** Windcube 200S (Windforge)
  - **Lufft:** CHM8k and CHM15k (**Lufft Viewer**)
  - **Vaisala:** CL31 and CL51 (**CL-View And BL-View**)
- Development of Common Algorithm for MLH

Unified Ceilometer Network (UCN)

Data Products

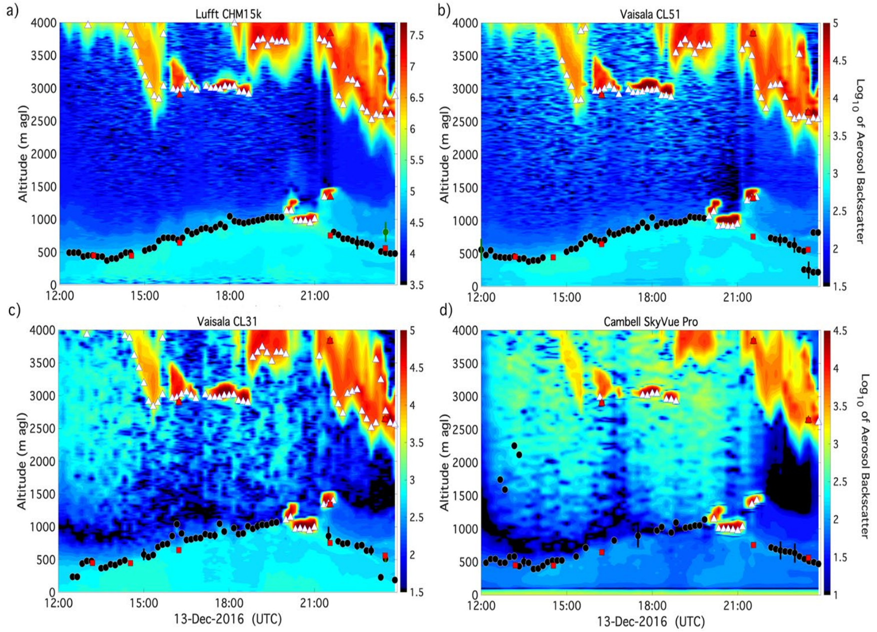
- **Over 40 PAMS locations**:
  - First sites with continuous boundary layer profiling collocated with a large suite of other measurements: Ambient air database (met, $PM_{2.5}$, O_3,NO_2, NOx, speciated VOCs and $PM_{2.5}$) PAMS+NCore
  - A select number of sites host Pandora spectrometers as an enhanced monitoring instrument.

- **Near real-time data processing** (MLH, NBL, residual layer (RL), aerosol layers)
  - Near real-time particle pollution detection (e.g. haze,smoke,dust)

- **Development of standardized retrieval algorithms** for heterogeneous network
  - Automated PBL algorithm corrects for instrument signal quality, screens for precipitation and cloud layers, and provides PBLH uncertainties.
  - Ceilometer aerosol backscatter profiles are used to determine the PBL height with continuous 10-minute temporal resolution (Caicedo et al. 2020).

PBL Automated Outputs:

- Cloud-base heights
- Precipitation flags
- Filtered PBL heights (NSL, RL, MLH)
- Uncertainties for PBL heights



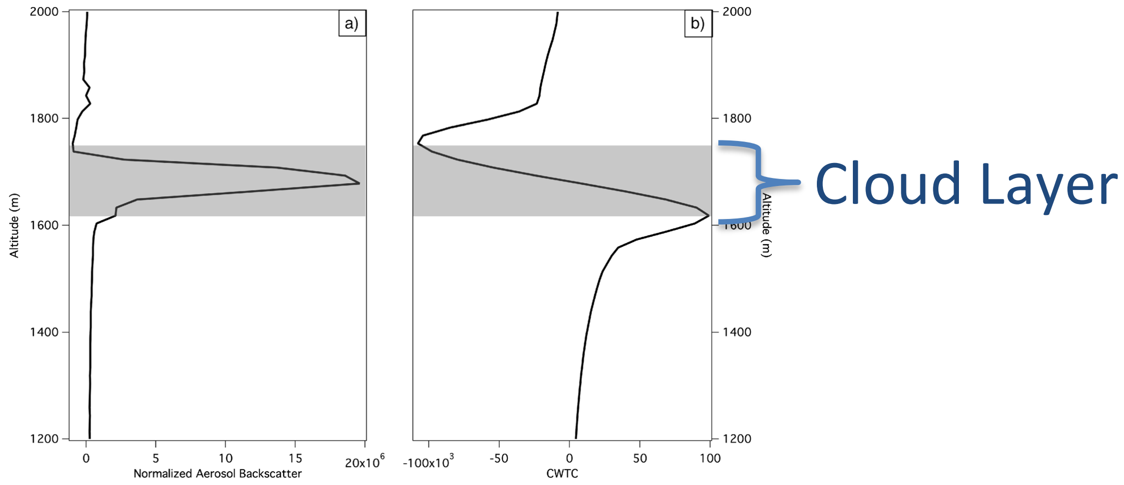
Caicedo et al. (2020)
https://doi.org/10.1175/JTECH-D-20-0050.1

Planetary Boundary Layer Height Algorithm

Development of standardized retrieval algorithms for heterogeneous network

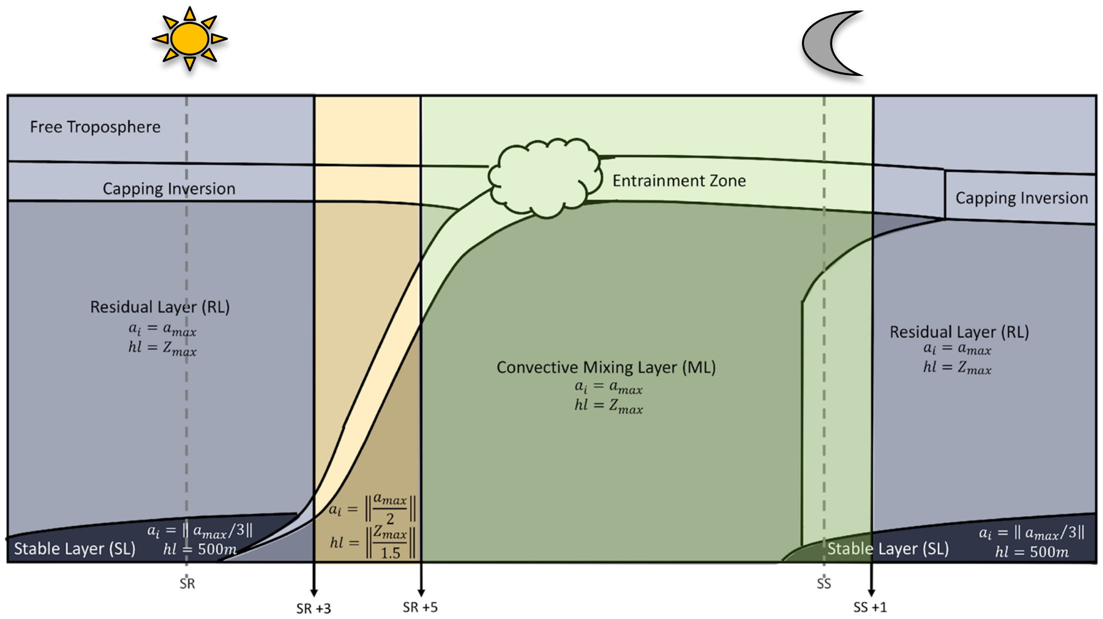
Automatically screens for clouds and precipitation

- Derive cloud layer heights using the Haar wavelet retrieval methodology



Aerosol backscatter   Wavelet Transform

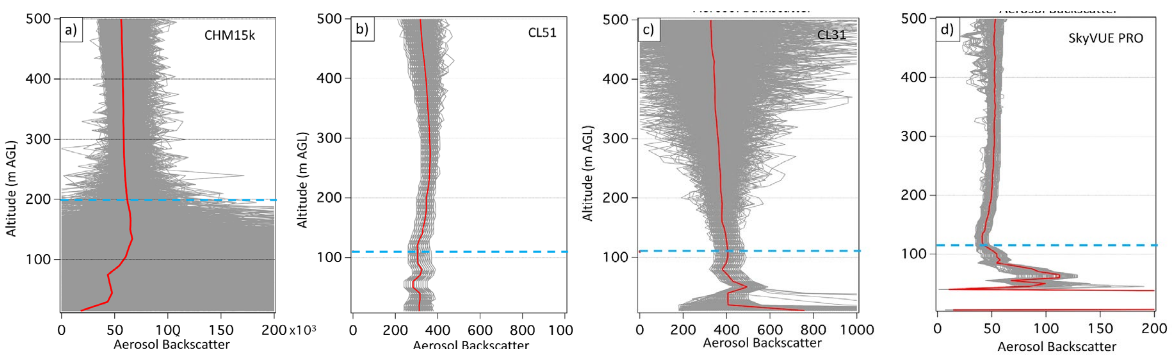
Layer attribution for the PBL height is supported with the use of continuation and time-tracking parameters



Planetary Boundary Layer Height Algorithm

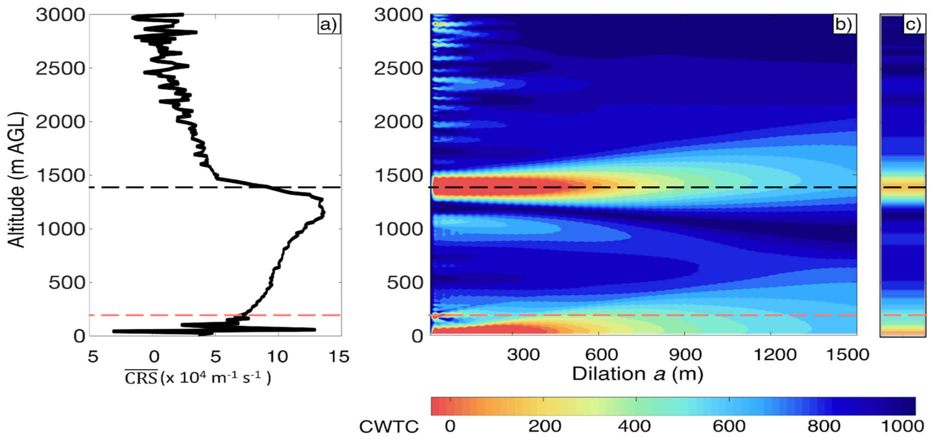
An Automated Common Algorithm for Planetary Boundary Layer Retrievals Using Aerosol Lidars in Support of the U.S. EPA Photochemical Assessment Monitoring Stations Program

Addresses instrumental signal quality (SNR, artifacts, overlap, etc.)



Define minimum reliable signals and limitations

Haar step-function to detect changes in aerosol backscatter profiles using multiple dilations



Common retrieval algorithm for heterogeneous network with proper QA applied

Caicedo et al. (2020)
https://doi.org/10.1175/JTECH-D-20-0050.1

QA/QC and Calibration/Validation

- ASTM International
  - Standard Guide for Mixing Layer Height from Laser Based Ceilometers
- U.S. EPA Methods Document/Quality Assurance Project Plan (QAPP)
  - Quality Assurance for Ground Based Ceilometers
- European Cooperation in Science & Technology
  - **PRO**filing the atmospheric **B**oundary layer at **E**uropean scale (PROBE)
- Ad-hoc Ceilometer Experiment Study (ACES)
  - Evaluation of Lufft Cloud Simulator and Vaisala Termination Hood
  - Vaisala CL61
- Educational Materials
  - Introduction to Ceilometer: Instrumentation and Data Interpretation

NWS Priorities for Weather Research (PWR)

UMBC

Observations and Data Assimilation (OD) Priority Area 3:
Observations Gaps and Use and Assimilation of New Observations (OD-6):

Develop and deploy a national boundary layer, soil moisture and aerosol observing system - to improve research and prediction at the interfaces with other Earth system model components

Critical Actions for OD-6:

OD-6.1. Develop a coordinated national profiling network over land with an offshore extension to routinely collect observations within the lower troposphere, observing the atmosphere from the ground up. Continuous profiling at high temporal frequency and vertical resolution is dictated by dominant temporal and spatial scales of processes within the PBL. To close the extant PBL observational gap, the proposed NOAA ground-based PBL observing network should be complemented by satellite, surface-based, and airborne measurements in a hybrid observing system.

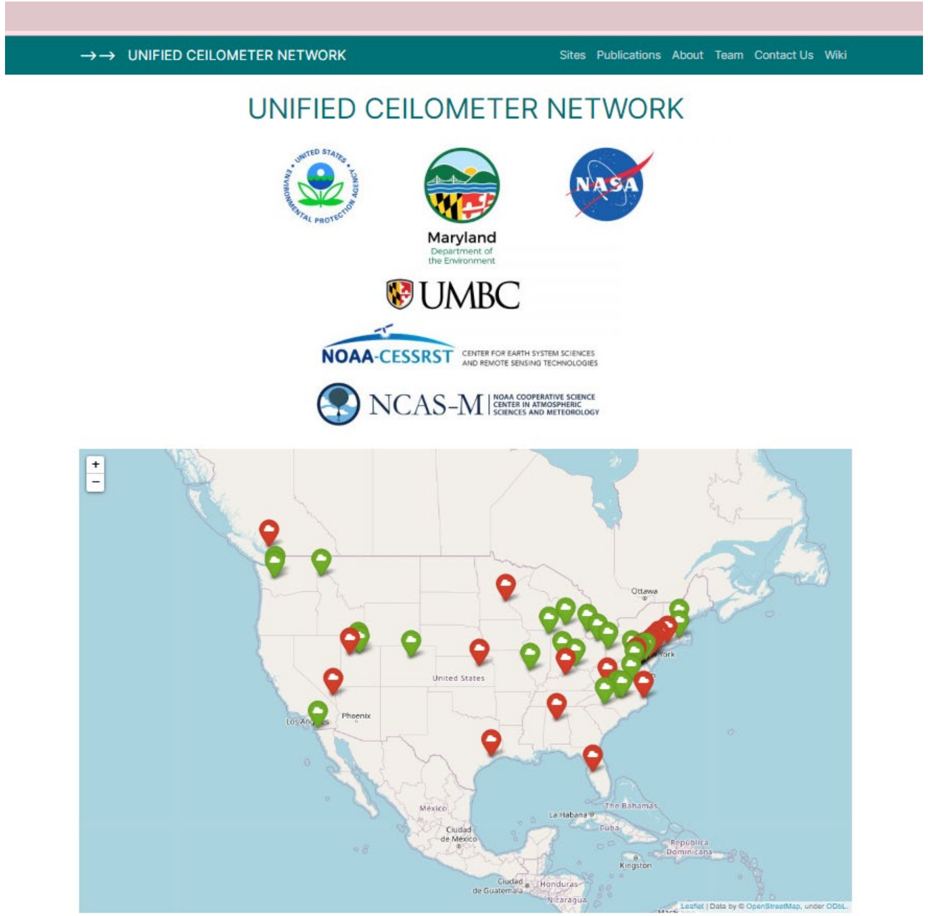
OD-6.2. Support collaborations between those designing and implementing the ground-based PBL system and those involved in data assimilation. The objective of these collaborations would be two-fold: to use data assimilation experiments to advance the design of the network, and to ensure that new observations can be assimilated immediately after the observational system testing and evaluation has concluded.

OD-6.3. Support partnerships between NOAA, and the academic and private sectors, to design and implement such a national network and will help advance the NOAA mission.

OD-6.4. Develop and deploy ground-based remote sensors that measure smoke plume insertion altitudes and its down-mixing and deposition to the surface and assimilate the data into numerical models. Develop and deploy airborne sensor packages to measure vertical profiles of smoke and aerosol concentrations and chemical makeup, by leveraging existing weather sensor and communication capabilities on commercial aircraft and their inherent ascent and descent flight patterns. Assimilate these observations into numerical models to improve wildfire prediction.

https://sab.noaa.gov/wp-content/uploads/2021/12/PWR-Report_Final_12-9-21.pdf

Unified Ceilometer Network (UCN)



https://ucn-portal.org

- When your site becomes Active (data transfer from AQ monitoring site/agency to UCN processing server) your UCN webpage will go live.
- Active sites in new data portal have green icons in map.

Dynamic Data Visualization

UNIFIED CEILOMETER NETWORK

Sites Contributors Resources

Maryland
Department of the Environment

Date: 2021-12-06

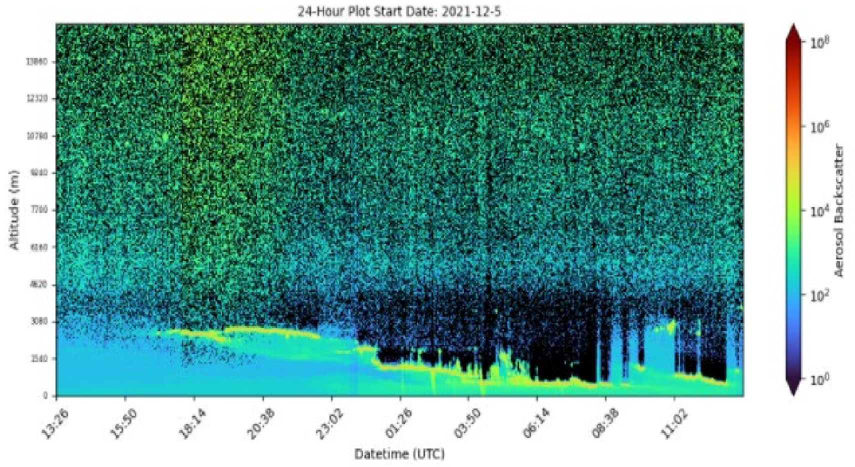
Max altitude: 15400 m

Colormaps: turbo

Reverse:

Colorbar max: 8

plot



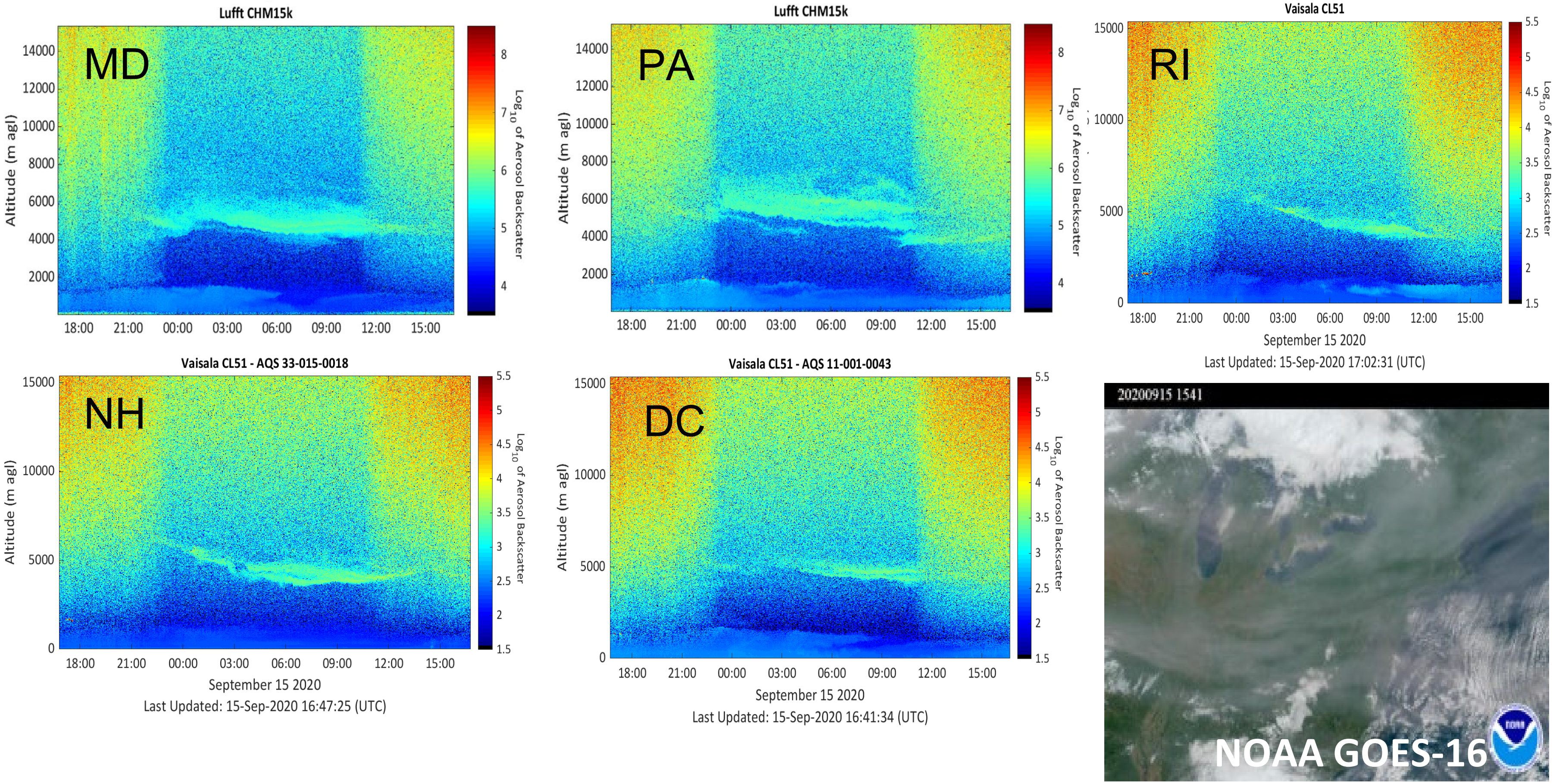
Site PI	Latitude	Longitude	Elevation ASL (m)	Wavelength (nm)
Adam Reese	39.3108	-76.4744	15.00	910.00

View Archive

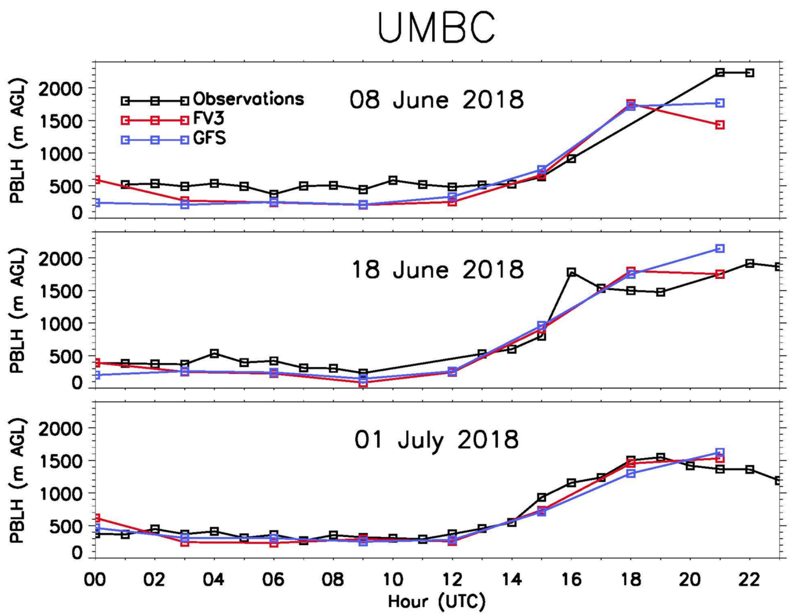
- Last 24 hours of observations are displayed
- User selection:
  - Max. altitude
  - Colormaps
  - Colorbar
- Calendar: Selection of data for any day
  - 24-hours is plotted
- Netcdf file of 24-hour observations
- Email notifications
- Data Download (daily and multiple days)

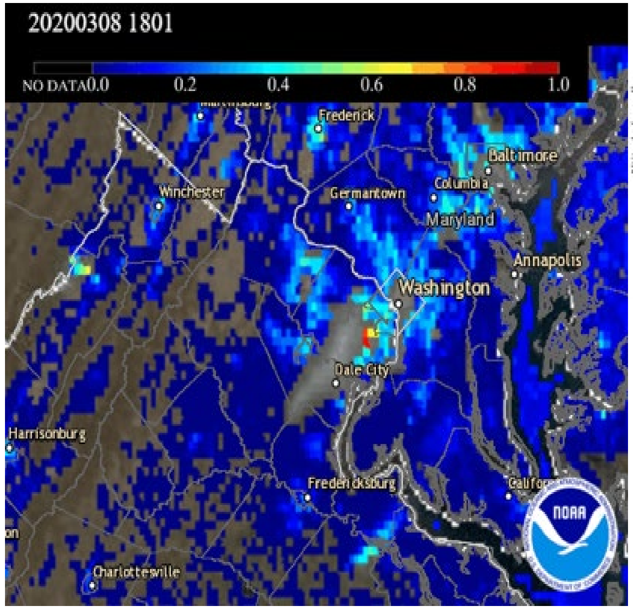
Tracking Vertical Altitude of Smoke

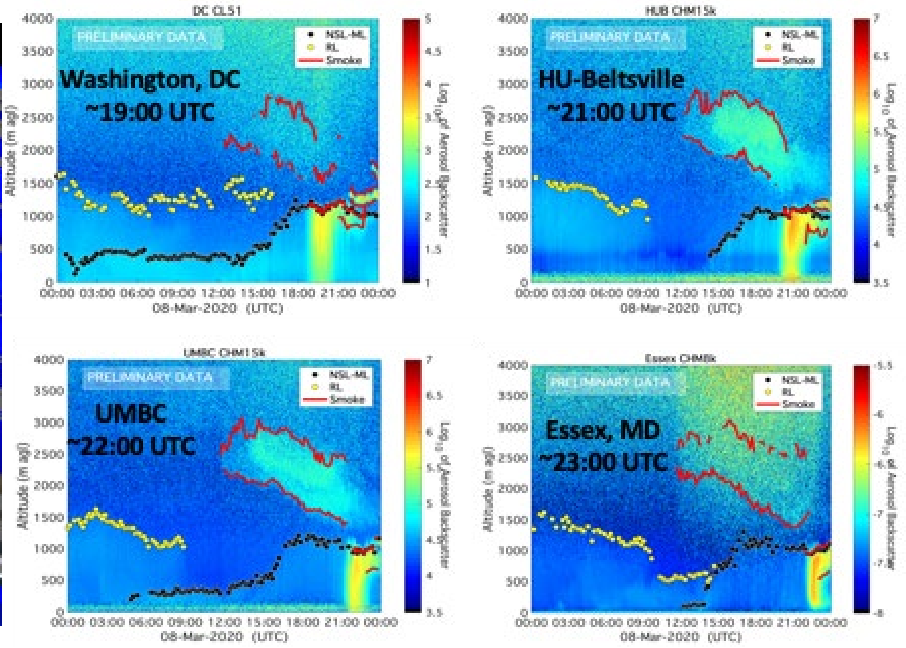
California Wildfire Smoke Transport to Eastern U.S.
September 15, 2020



Verification/Validation of Models and Satellite Products







PBL Height:
Ceilometer vs NOAA FV3 and GFS model
(Loughner et al. 2019)

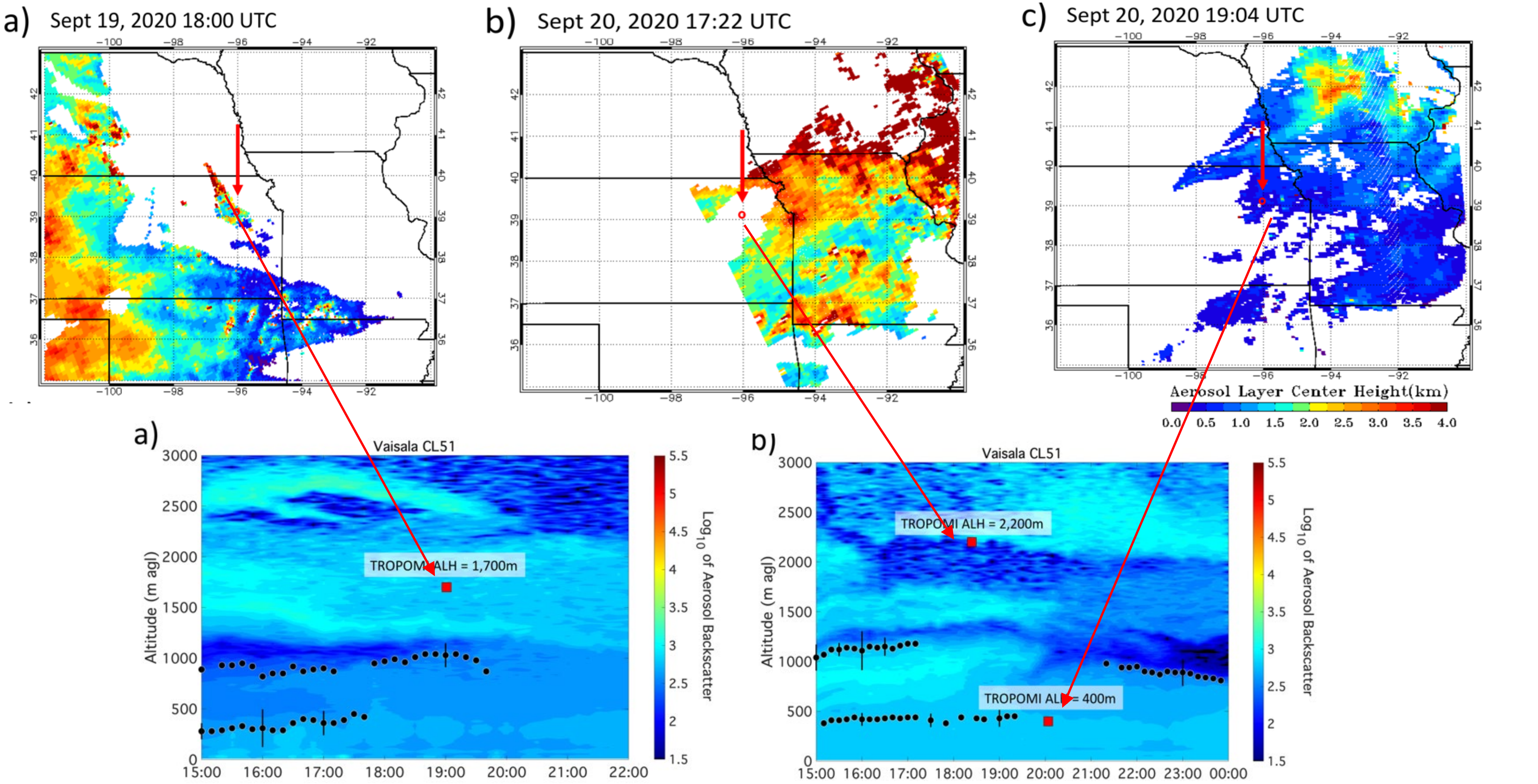
Smoke transport within PBL observed by ceilometers network supplementing GOES-16/ABI AOD
Huff et al. 2021
https://doi.org/10.1175/JTECH-D-20-0162.1

*Air Quality Case Studies and Exceptional Event Analysis

Satellite Validation of Aerosol Height

TROPOMI Aerosol Layer Heights

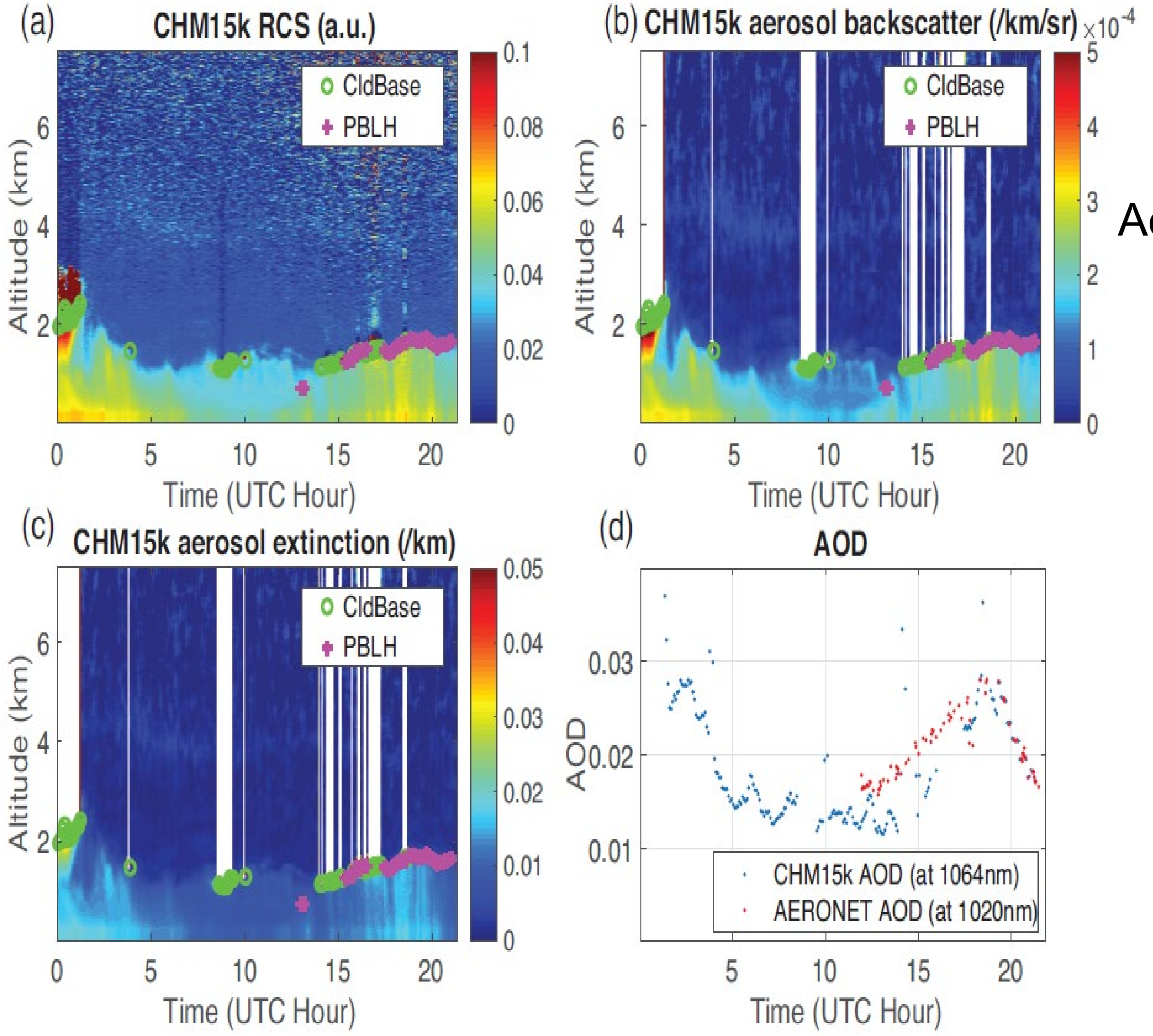
U.S. Region 7 CL51 at Konza Prairie Site



The UCN site in Konza Prairie, Kansas (EPA Region 7: 39.1022°N, 96.6096°W Bottom a-b) captured the evolution of the smoke plume transport. Ceilometer planetary boundary layer heights were calculated at the times of TROPOMI measurements and contrasted against TROPOMI ALH (Top a-c).

Source: Caicedo (UMBC)/Wang (Univ. Iowa)

Improve Column to Surface Pollution



Capabilities of an Automatic Lidar Ceilometer to Retrieve Aerosol Characteristics within the Planetary Boundary Layer
Li et al. 2021, Remote Sens. 13, 3626

Above and Below PBLH Aerosol Optical Depth (AOD):

Aerosol vertical distribution or range-resolved information is also important to better connect satellite-measured AOD to the near-surface $PM_{2.5}$

UCN Data Products

Measurement /Retrieved Parameter	Analysis Method	Derived parameter	Sampling Frequency	QC Check
Mixing Layer Height	Haar wavelet algorithm	PAMS -Hourly Mixing Layer Height	10 min average MLH generated as common sample frequency	Visual check of data and products using aerosol backscatter and MLH
Residual height layer	Haar wavelet algorithm	PAMS - Hourly residual Layer Height	10 min average MLH generated as common sample frequency	Visual check of data and products using aerosol backscatter and MLH
Aerosol Backscatter	measured	**Non-PAMS derived parameter**	Varies by ceilometer 15-36 seconds	Visual check of data and instrument diagnostics monitoring
Aerosol layers	Haar wavelet algorithm	**Non-PAMS derived parameter**	10 min average generated as common sample frequency	Visual check of data and uncertainty evaluations
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
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

Secure Data Transfer

Migration of data transfers:

- Currently ftp data transfer to alg.umbc.edu will be phased out
- New data transfer protocol → https/API key

1- This requires that UMBC has remote access to instrument

2- To coordinate migration, we are verifying and updating agency/organization contact person for each site. Contact persons for each site can be found here:
https://www.ucn-portal.org/sites

3- Site information can be updated at any time, in addition to request to joining network
UCN Google Form:
https://forms.gle/jBNypgacZc3FHs597

4- Contact portal.ucn@gmail.com for UCN related questions.

Next Steps

Display Mixing Layer Height

Create a notification system for sites not sending data

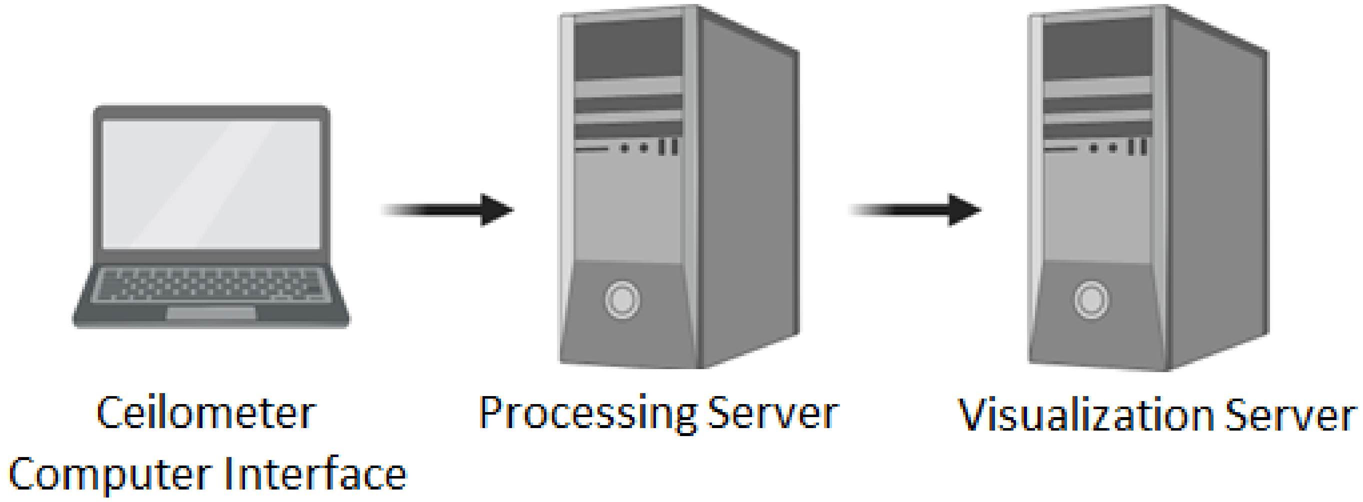
Implement data download for registered ”researchers”

Fix front-end issues

Upgrade Visualization Specs

Creating integrations tests

Improve testing of front-end



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- Working internet connection
- Administrator rights or the ability to obtain one for the ceilometer computer interface

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Summary

- **Vertical and temporal resolution of lidar allows:**
  - Assessment of long-range transport of natural and anthropogenic aerosols vs. local sources to local air quality.
  - Aid source allocation of particle pollution for during Air Quality Action Days. Evidence for Exclusion of Air Quality Exceedance due to Exceptional Events.
  - Continuous monitoring of PBL –verification and validation of satellite, forecasts and models.
- **Lidar + real time ground monitoring of pollutants: Characterization of temporal and spatial changes of particle pollution, oxidants, and precursors.**

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Acknowledgements

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James Szykman (szykman.jim@epa.gov)

UMBC

Acknowledgements

- Environmental Protection Agency (SCIENCE SYSTEMS AND APPLICATIONS, INC SUBCONTRACT # 21606-18-057) and NASA/JCET Task 196

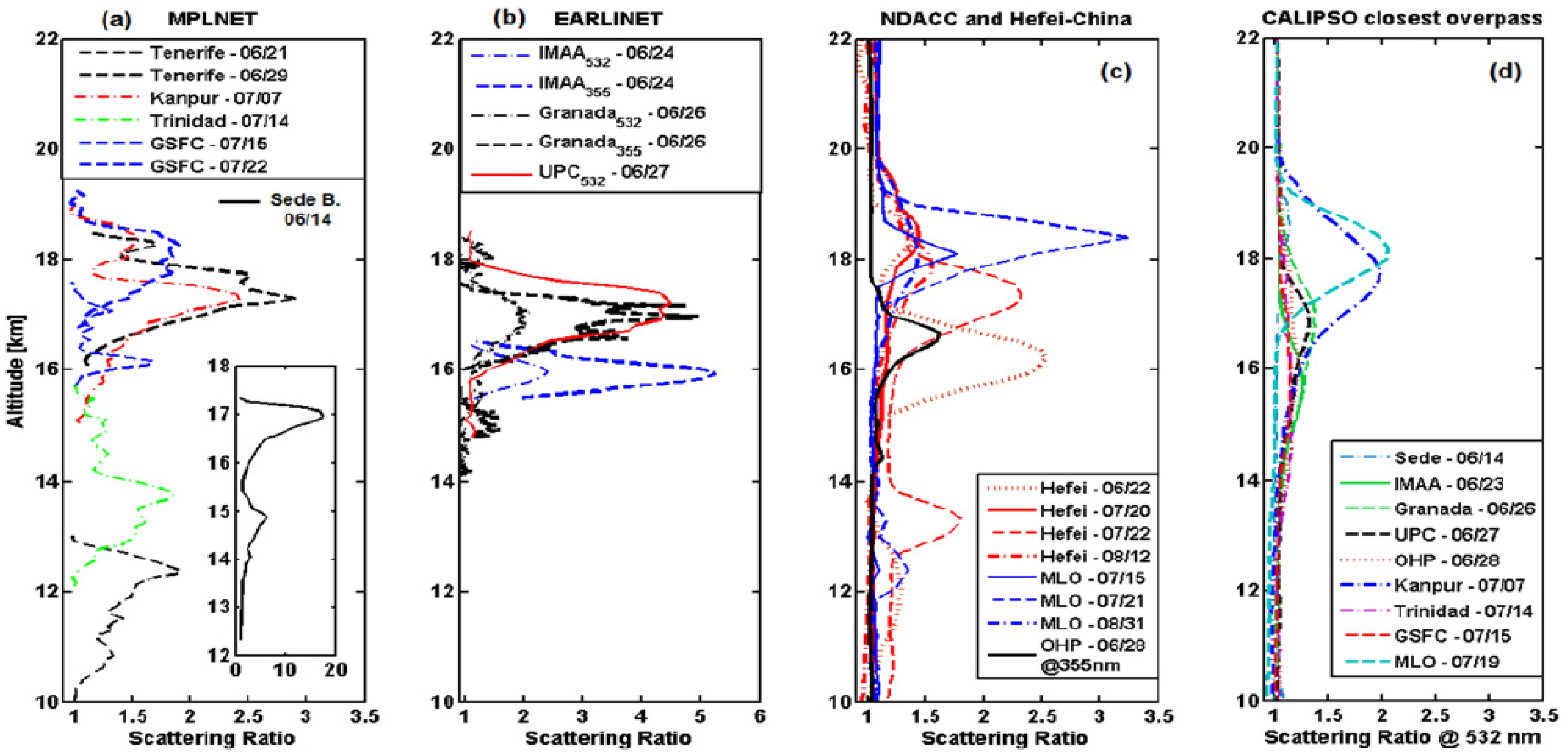
- NOAA Cooperative Science Center ESSRST: Grant # NA16SEC481008

Interested in joining UCN

Table 1. Commercial Ceilometer and software used

Ceilometer	Logging Software	Resolution / Range / Reported Range	Reported Backscatter Corrections
Vaisala CL31	CL-View	10m / 0 – 7.7 km / 0 - 7.7 km	Background, range and overlap corrected
Vaisala CL51	BL-View	10m / 0 – 15 km / 0 – 4.5 km	Background, range and overlap corrected
Lufft CHM15k	Lufft Viewer	15m / 0 - 15 km / 0 – 15 km	Background, range and overlap corrected
Campbell Sci. CS135	Viewpoint	5m / 0 – 10 km / 0 – 10 km	Background, range and overlap corrected

Nabro Volcano: 13 June 2011



- The globally averaged AOD due to the stratospheric volcanic aerosol layers was 0.018 at 532 nm, ranging from 0.003 to 0.04.
- Compared to the total column AOD from AERONET stations, the stratospheric contribution varied from 2% to 23% at 532 nm.

Sawamura et al. Environ. Res. Lett. 7 (2012)

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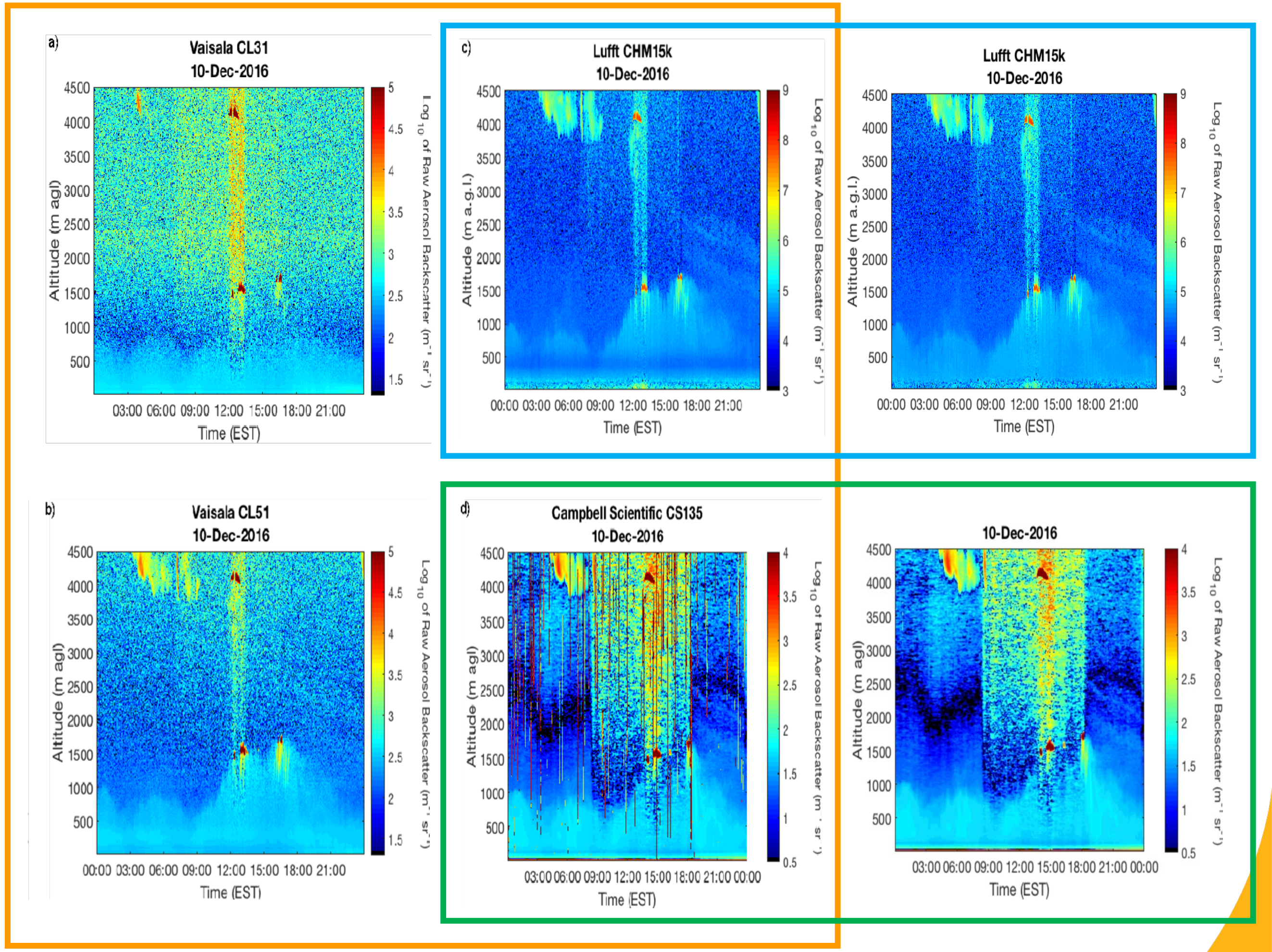
Ceilometer Signal Evaluation

- Varying signal quality
  - QC/QA protocols per make/model
- Ceilometer signal evaluation/correction*
  - **Signal-to noise ratios**
  - **Overlap corrections**
  - **Artifacts**
  - Resolution



*(O'Connor et al., 2004; Wiegner and Geiss 2012; Hervo et al. 2016; Kotthaus et al. 2016, among others)