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Determination of Mixing Layer Height and ASOS: Testbed, Algorithms and Network

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Atmospheric Lidar Group
Joint Center for Earth Systems Technology
University of Maryland, Baltimore County

International Cooperative for Aerosol Prediction (ICAP)
8th Working Group Meeting:
Lidar Data and Its Use in Model Verification and Data Assimilation
July 13, 2016

UMBC Atmospheric Lidar Group
Research Areas

•Inversion algorithms, optical, chemical and physical properties of atmospheric aerosols, gases, and clouds.

•Boundary Layer Dynamics (Air Quality and Wind Energy)

•Continental and intercontinental plume transport to Eastern US and Caribbean.

•AOD-$PM_{2.5}$ Estimator Development from Ground, Satellite Observations, NWF and Global Models

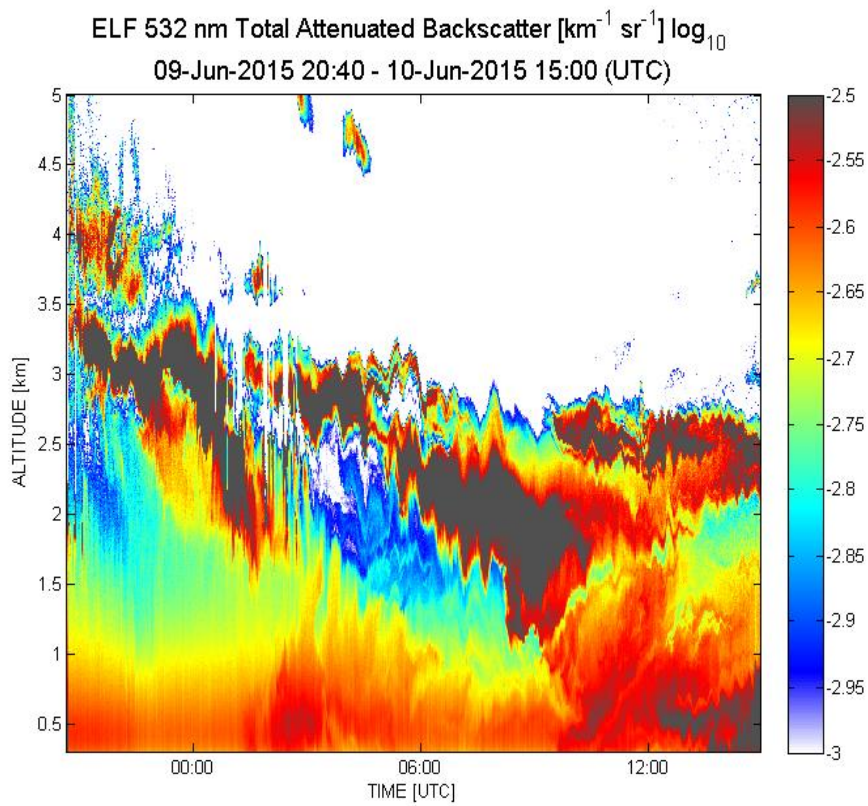
•New remote sensing technologies for atmospheric observations.

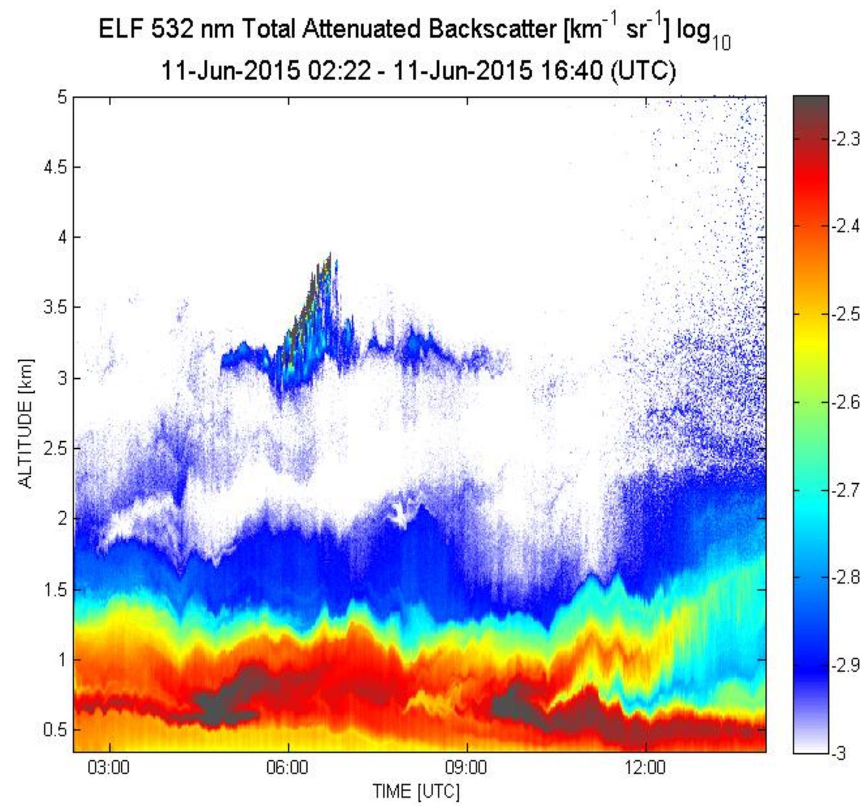
Mixing Layer Height (MLH)

- Diagnostic variable atmospheric transport and dispersion forecasting models.
- Without realistic MLH models have large errors that result in inadequate public protection against unhealthy air quality.
- National Research Council has recommended a "network of networks"[1]
  - After 60 years of remote sensing research, it is astounding that the PBL is not measured regularly throughout its diurnal cycle

1- NRC. 2009. *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks*. Washington, DC: National Academy Press.

June 2015 Canadian Smoke Event



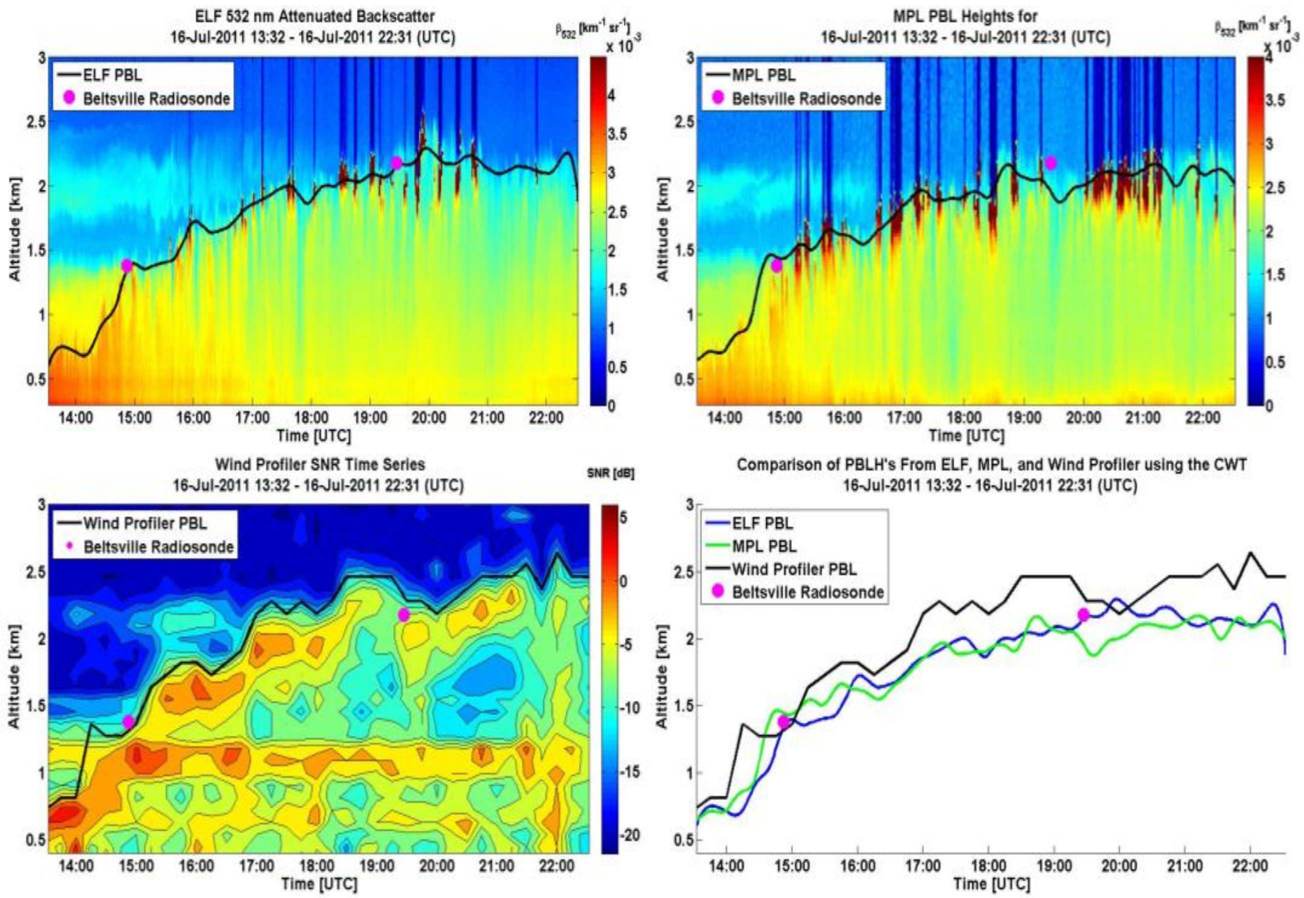


Elastic lidar backscatter image shows aerosols aloft (1.5-3 km) on June 10th. The particles began to mix causing increased near surface particle pollution.

The 11th shows a homogenous layer, smoke mixed with the mixing layer which extends up to 1.5 km.

UMBC Smog Blog: http://alg.umbc.edu/usaq

MLH Algorithms



• Lidar and wind profilers MLH can provide continuous temporal resolution atmospheric profiles for verification and validation of forecasts and models, on whether the physics and dynamics packages are correct in models.

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

Joint NOAA/ARL NOAA/NCEP Field Study- September, 2009

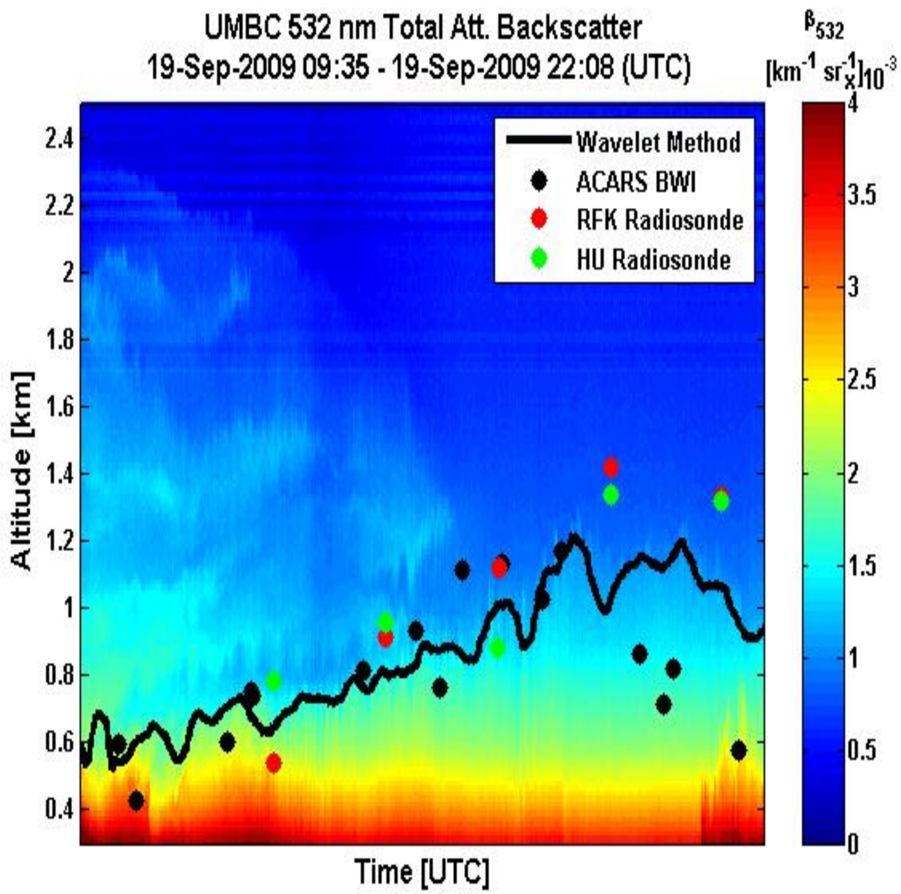
1-Develop an urban meteorological evaluation database to investigate the evolution and spatial variability of the urban atmospheric boundary layer mixing height.

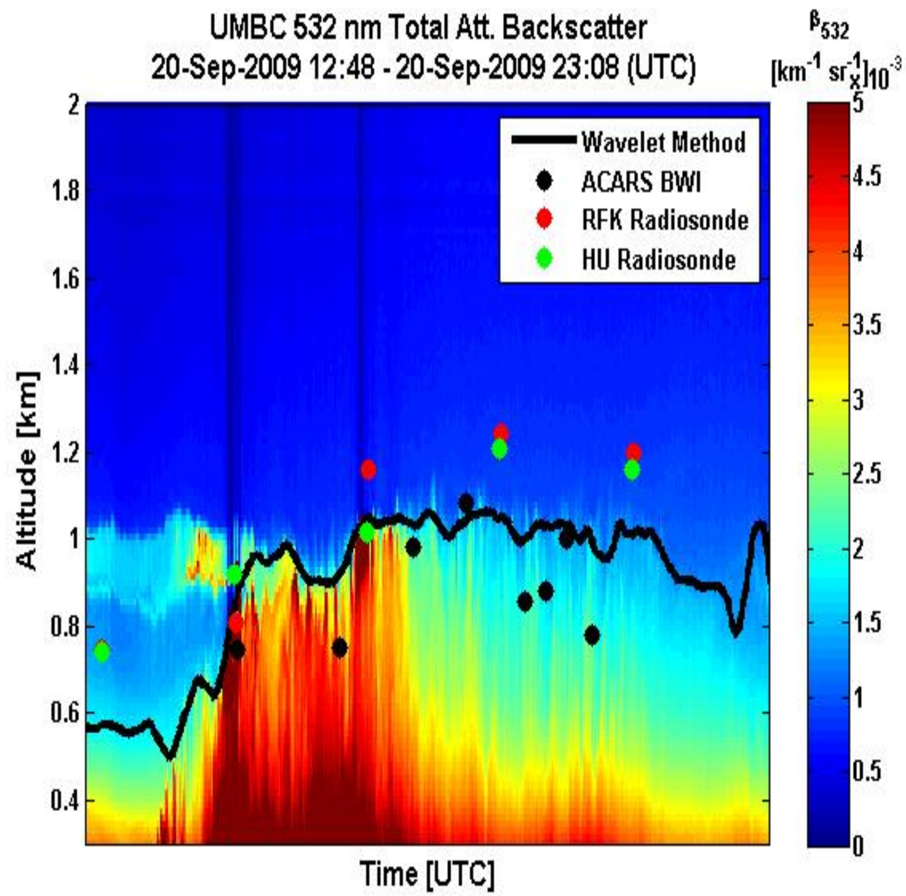
2-Evaluate various instrument platforms for detecting mixed layer height.

3- Accurate assessment of boundary layer information at finer scales should improve the Nation's ability to assess the effects of a toxic release (in support to Homeland Security).

*Project supported demonstration of NOAA's Real-Time Mesoscale Analysis (RTMA) of PBL information for use by plume dispersion modelers.

Joint NOAA/ARL NOAA/NCEP Field Study





Lidar measurements helped to identify problems with automatic PBLH calculation from aircraft profiles (ACARS).

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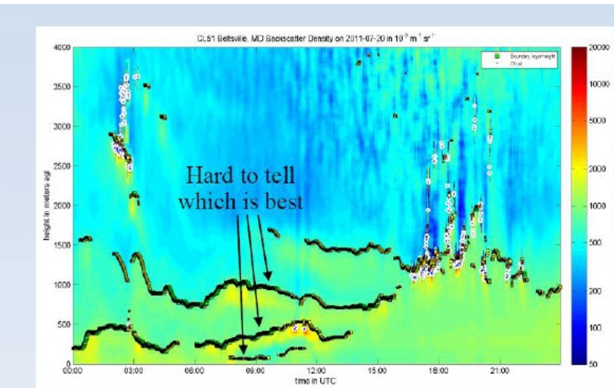
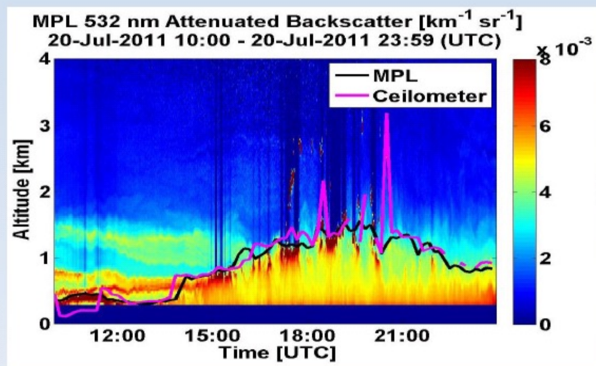
Algorithm Comparison

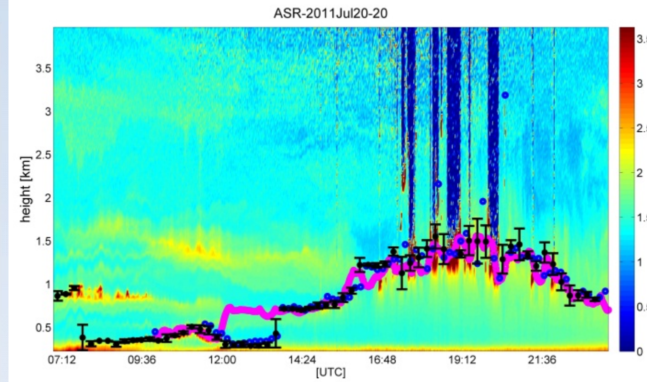
DISCOVER AQ Summer 2011 @ Beltsville, MD



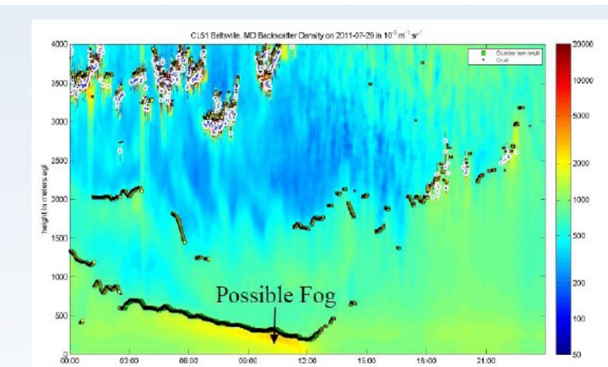
CL51 Ceilometer

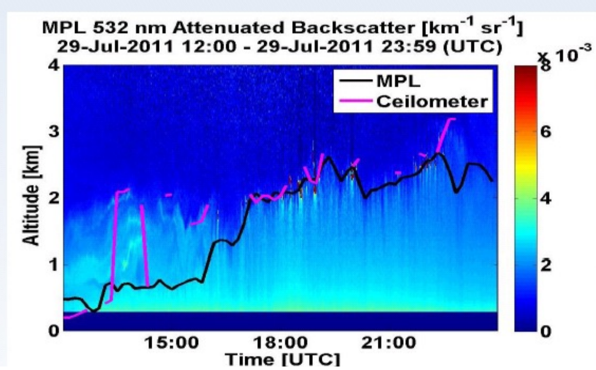


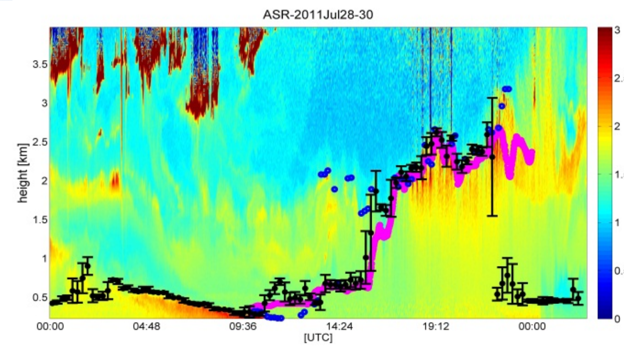
MicroPulse Lidar (MPL)



Howard Raman Lidar







Laser: InGaAs
Power: 8.9 mW
Wavelength: 910 nm
Algorithm: BL-View

Laser: Nd-YLF
Power: 25 mW
Wavelength: 532 nm
Algorithm: Wavelet

Laser: Nd-YAG
Power: 8 W
Wavelength: 355 nm
Algorithm: Wavelet

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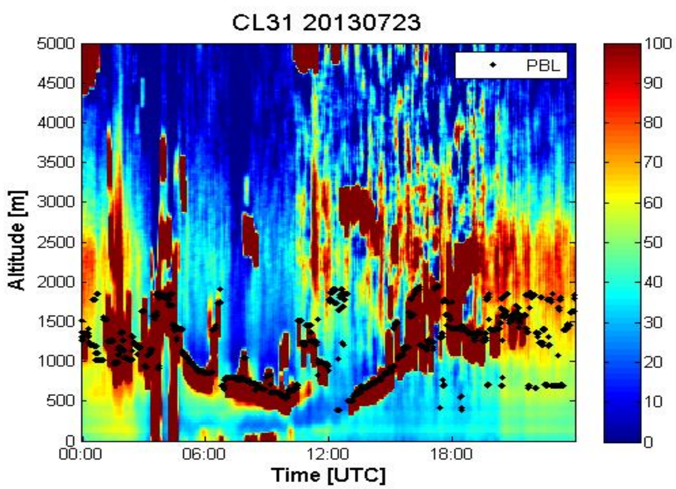
Recommendation of Ceilometer PBL Heights for Assimilation/Verification of Forecast Products

***UMBC**: Belay Demoz, Ruben Delgado, Kevin Veermesch; **Howard University:** Ricardo Sakai; **NWS:** Dennis Atkinson, Michael Hicks, Jason Chasse (Program Manager NextGen Aviation Weather at NOAA/NWS/ OS&T)*

- UMBC algorithm being used to retrieve MLH from the NWS Vaisala's CL31 ceilometers, as part of a Proof of Concept CL31 Test bed.
- The algorithm development for MLH from CL31 ceilometers to be implemented at nationwide ASOS sites, as support of scientific efforts of the NWS Sterling Field Support Center.



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Determination of Planetary Boundary Layer Height with Doppler Wind Lidar

Qin Liu[1], Brian Carroll[1], Thomas Rieutord[2], Alan Brewer[3], Aditya Choukulkar[3], Ruben Delgado[1]

[1]University of Maryland, Baltimore County, Baltimore
[2]Météo-France, Toulouse, France
[3]National Oceanic and Atmospheric Administration

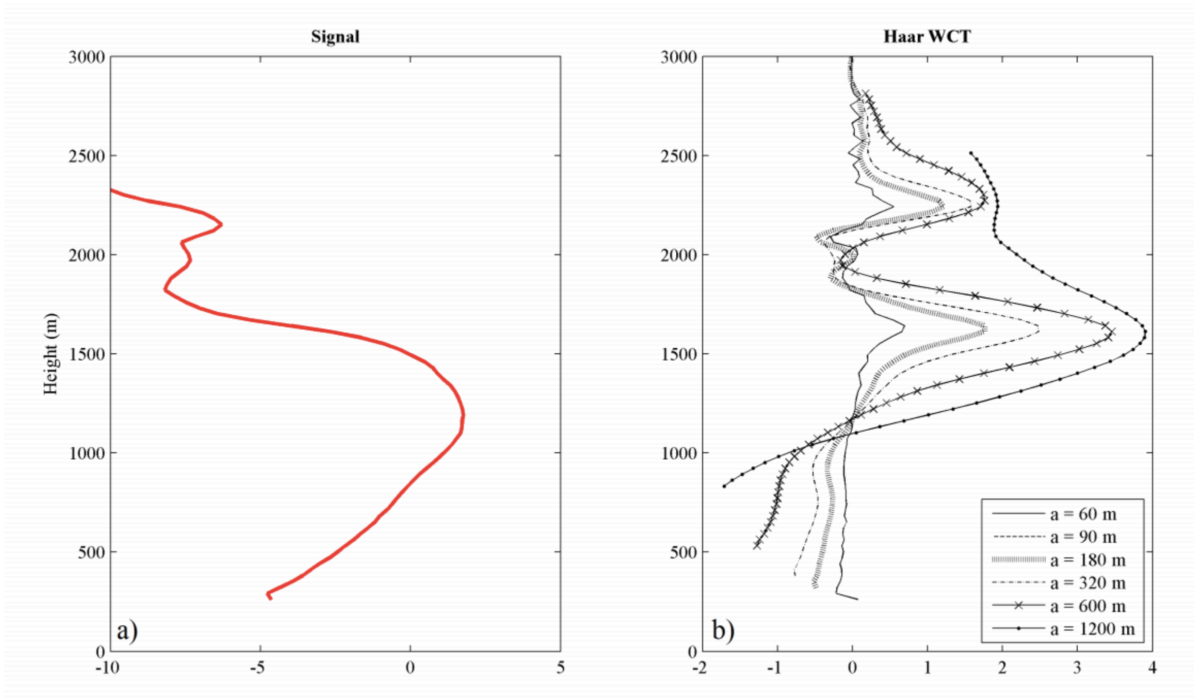
- Collaboration with NOAA ESRL.
- The purpose of this study is to evaluate the planetary boundary layer height retrievals from Doppler wind lidars.
- Analysis was applied to data collected from the two lidar systems during the July-August 2014 Discover AQ and LUMEX campaigns.
- This comparison aids applications in air quality and wind energy forecasting.

Peak Detection Method

Using Haar Wavelet Transform

$$\psi_H\left(\frac{z-b}{a}\right) = \begin{cases} -1, & \text{if } b-\frac{a}{2} \leqslant z \leqslant b \\ 1, & \text{if } b \leqslant z \leqslant b+\frac{a}{2} \\ 0, & \text{elsewhere} \end{cases}$$

$$W_f(a,b) = \frac{1}{a}\int_{-\infty}^{\infty} f(z)\psi_H\left(\frac{z-b}{a}\right)dz$$



Bowtie and Vertical Scan range-corrected intensity profiles and horizontal wind speed and direction.

Cluster Analysis

$$\text{Classic } K\text{-means} \quad w_k(\mathbf{P}^i) = \begin{cases} 1, & \textit{if} \quad \delta(\mathbf{P}^i, \mathbf{C}^k) = \min_{\ell=1\ldots K} \{\delta(\mathbf{P}^i, \mathbf{C}^\ell)\} \\ 0, & \textit{else} \end{cases}$$

K-means Algorithm

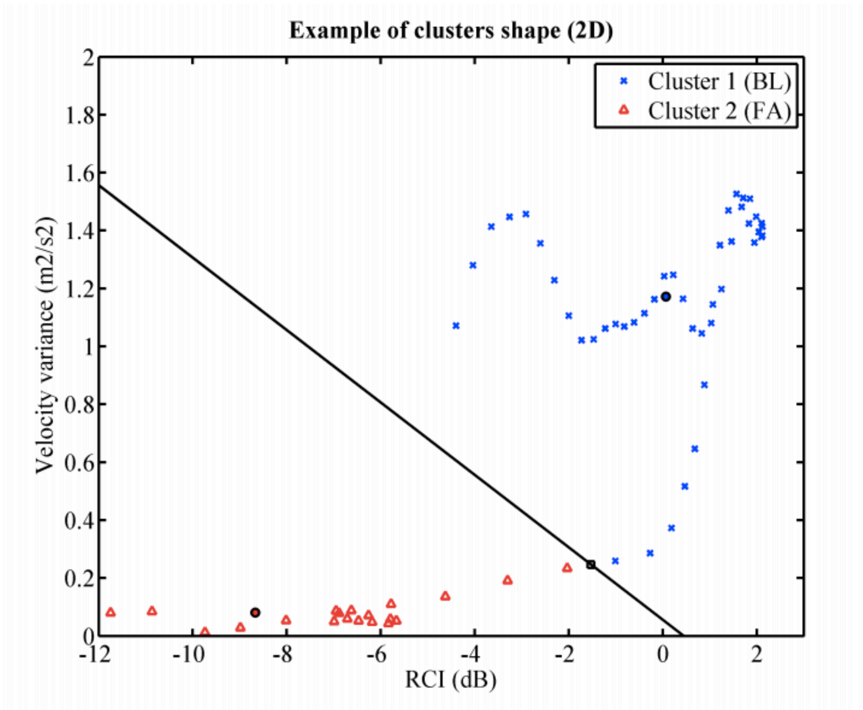
- Initialize the seeds (clusters)
- Calculate the distance from each point to each cluster
- Assign each point to the closest cluster
- Redefine the clusters as the centroid of points assigned
- Repeat the process until the intra-cluster variance no longer decreases

Initial Conditions

- Two clusters used, assign top half of the profile to one cluster and lower half to the other cluster

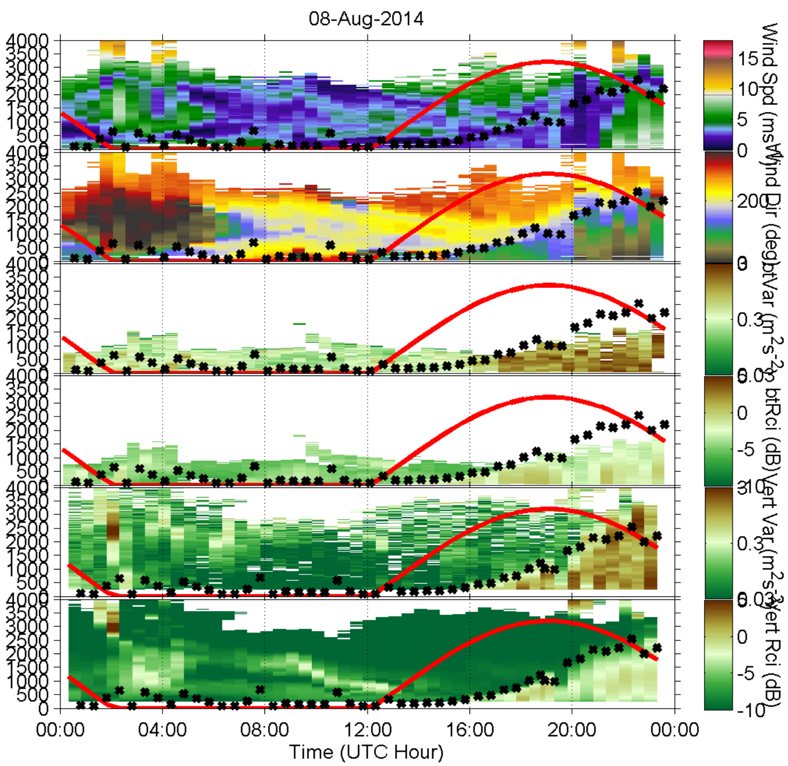
Convergent Test

- Calculate Euclidean distance between each point to the cluster and intra-cluster variance
- The algorithm stops when the intra-cluster variance are no longer decreasing
- The MLH is defined as the height where the cluster transitions

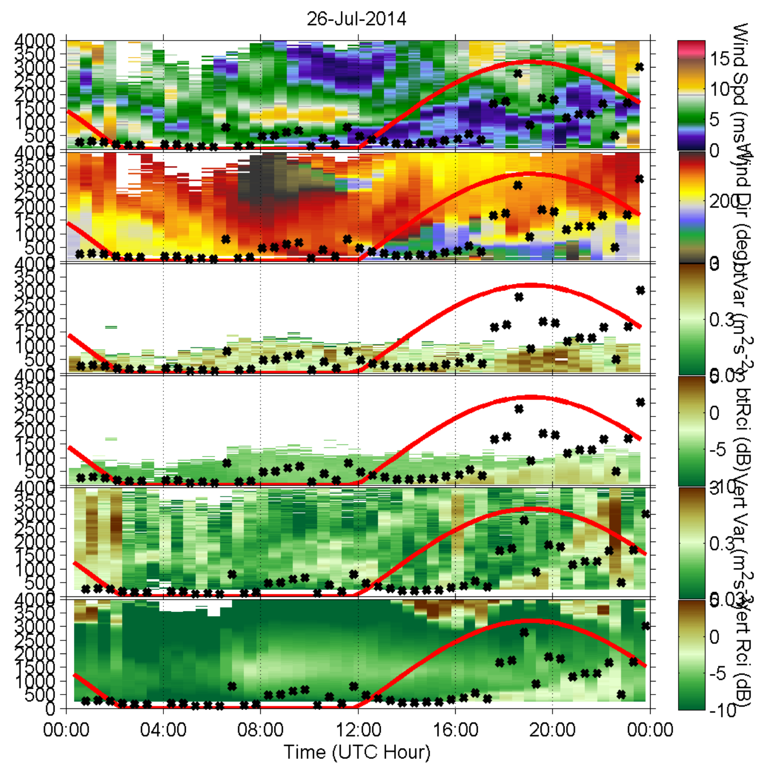


Cluster Analysis

Good



Bad



- Pros: faster than random seeding, results are consistent every time
- Cons: result is not accurate if there's missing data in one single profile
- Validation and Sensitivity of Algorithm is currently evaluated with PECAN Elastic, Raman, Doppler Lidar, Microwave Radiometer and Soundings data sets

Update:
Saving Ceilometer Data from the Automated Surface Observing System (ASOS)

ASOS Data: Motivation

NRC study: Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks (2009) → Thermodynamic Profiling Technologies Workshop 12-14 April, 2011

8.1 Recommendations

8.1.1 Improvement in the utilization of existing technology:
Ceilometers are underutilized for potential application in a TPT testbed. ASOS data is only now retained hourly with a one-minute o

Ceilometers!!!

ur. The operation of ASOS instruments throughout the hour is l … ata volumes from ASOS and transmission of those data should no … et 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 testbed of instruments should be developed in a region that has significant orographic, land use (i.e. urbanizatio

Regional Testbed

e of the region should be guided by difficulty in fore … plain changes, convective storms, etc. should be co … ch a testbed. The testbed should contain identical instrumentation at sites roughly placed 150km apart.

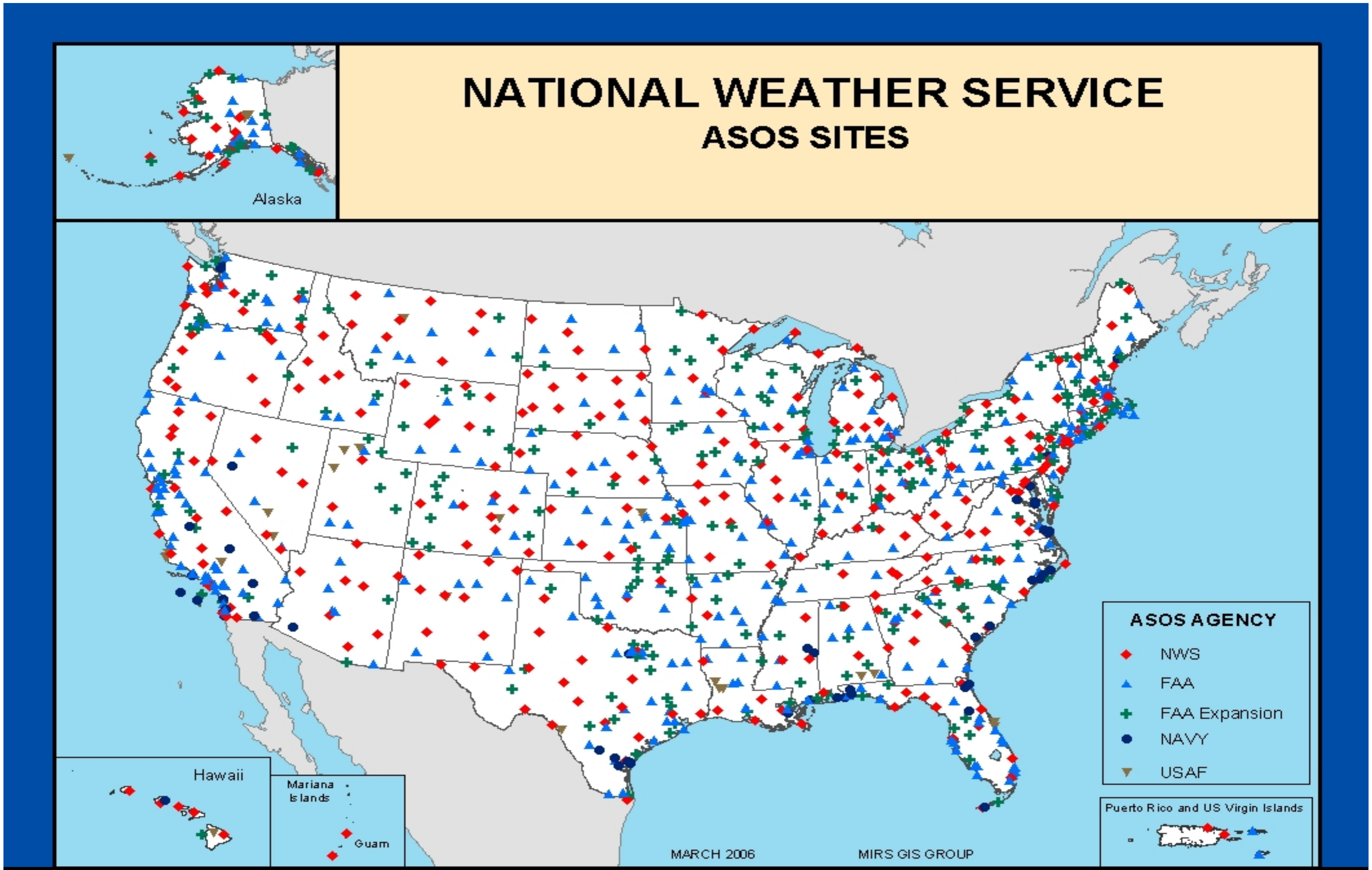
ASOS Ceilometer Workshop: NWS/Sterling, VA; March 22, 2012

- GOAL: *Describe how ASOS ceilometer backscatter data would be used if NWS could provide it.*
- ***What value would the data provide to the Nation?***

Needed to answer the following questions:

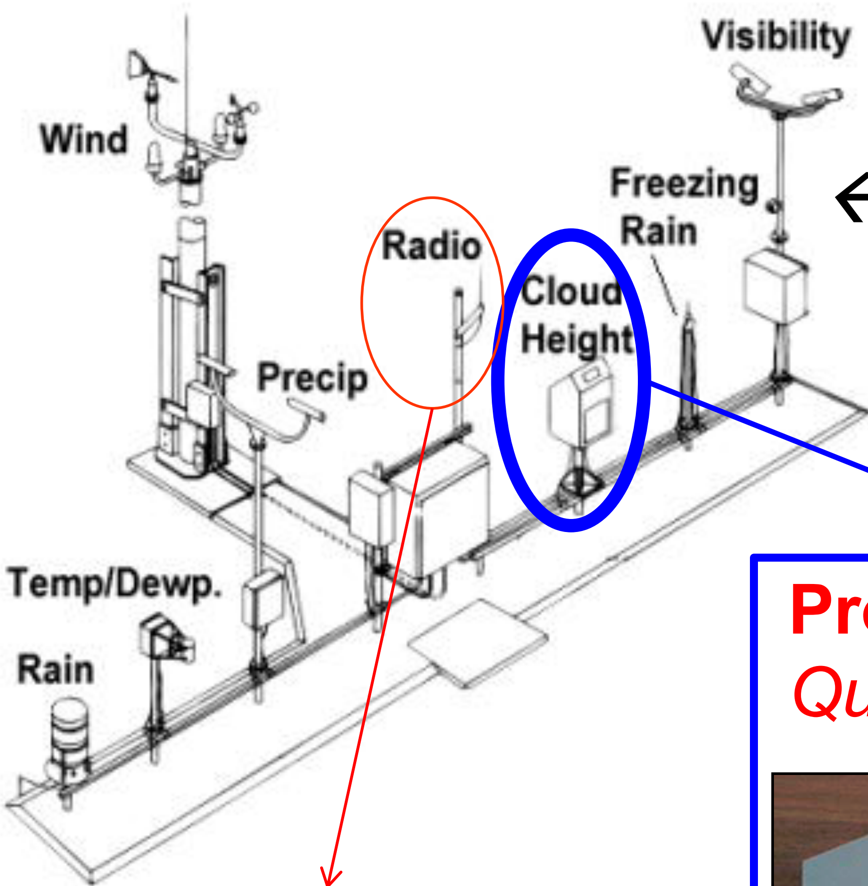
  - What data are available from the CL31?
  - What is the quality of the data?
  - How often is the data available?
  - How would the data be saved without operational interference.
- List the available applications for backscatter data
- Describe the research that is underway or required
- List challenges for research-to-operations (RTO)
- Chart a course of action to achieve goals

ASOS Ceilometer Sites

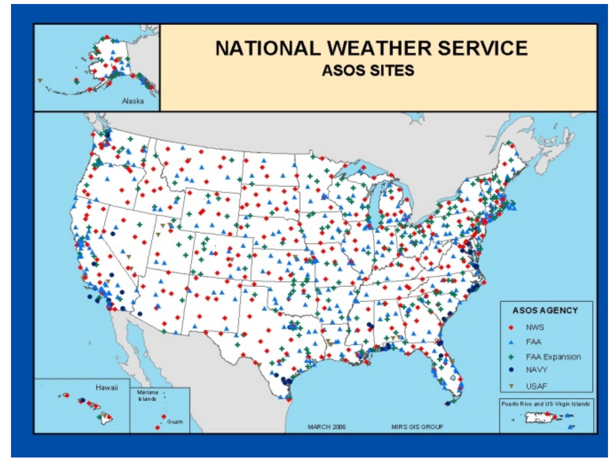


Chet Schmitt (OPS 22): ASOS Ceilometer Workshop, NWS/Sterling, VA. March 22, 2012

ASOS (Instrumentation/Issues)



← *Each ASOS*



Problem-1:
Quality of the lidars

Problem-3:
- *Inertia*
- *"Operational"!*

Problem-2:
Limited bandwidth transmission to main frame ASOS computer

Steps Required Before We Can Start …

ASOS CL31 Data Polling at NWS - Sterling, VA

Step 1: Collect and evaluate COTS ceilometer's profile data in a local network [***Completed***].

Step 2: Evaluate methods of Polling ASOS ceilometers for profile data without interfering with ASOS functions

Ceilometer profiles at 1min resolution were collected for months using a data logger

No interference observed that could be traced to the installation of the data logger on the ceilometer!

CL31: Case Studies List

Two Examples:

- PM-studies: ***Scaling Satellite-measured AOD and PM-Correlations***
- Night time convection: ***PECAN experiment [Elevated storm]***

More cases studies:

- Limited network of Ceilometer: ***Baltimore-Washington-area-Network***
- CL31 vs CT12 Vs CL51: ***An example of comparative data***
- CL31 data statistics: ***Cloud base above 12000 ft needs to be reported***
- PBL study: ***PBL from CL31: Multi-algorithm comparison***

More on Air Quality Applications

- Fire and Air quality: ***The case of 9-10 June 2015***
- Volcanic ash monitoring: ***How could ASOS help?***

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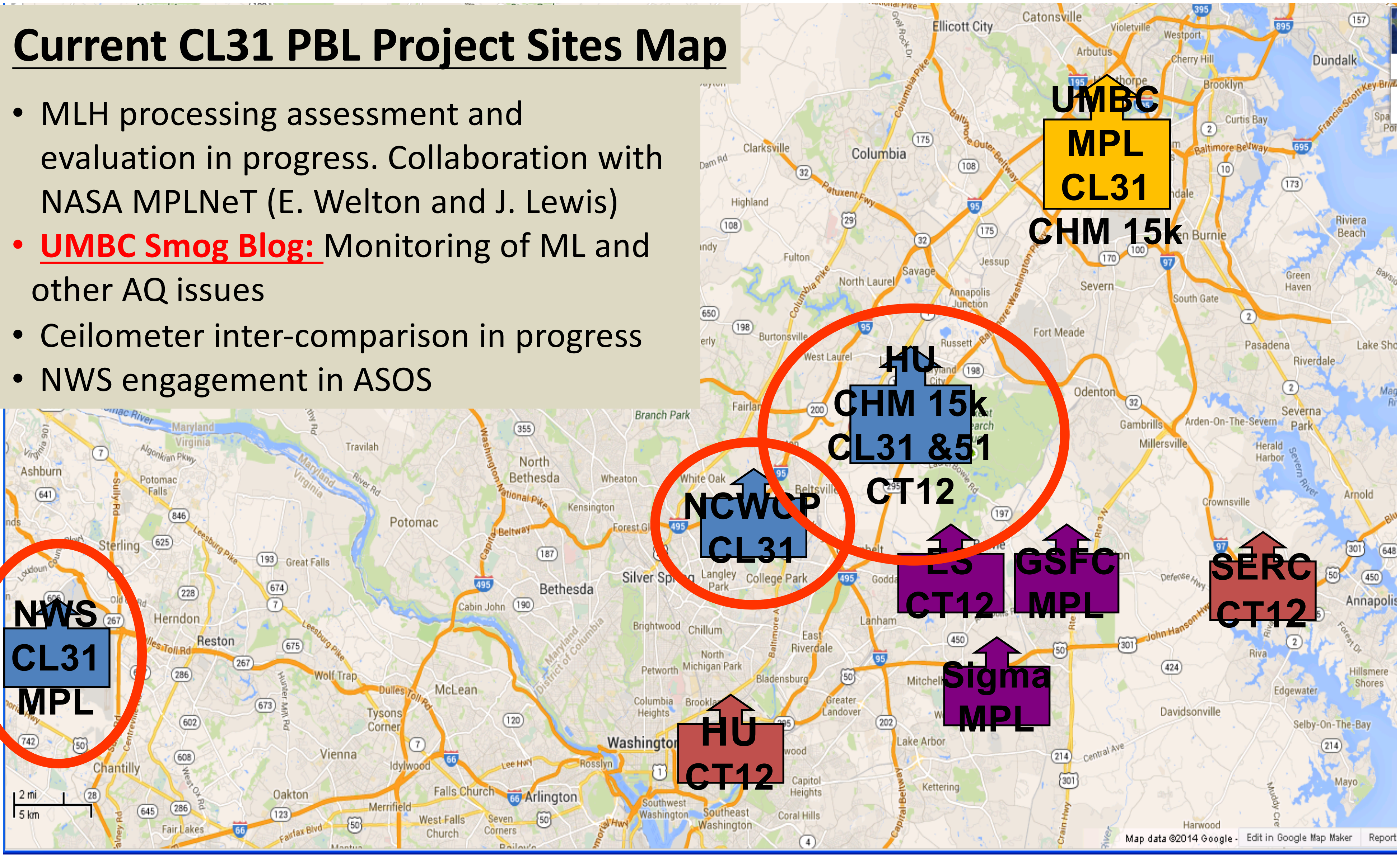
Current CL31 PBL Project Sites Map

- MLH processing assessment and evaluation in progress. Collaboration with NASA MPLNeT (E. Welton and J. Lewis)
- UMBC Smog Blog: Monitoring of ML and other AQ issues
- Ceilometer inter-comparison in progress
- NWS engagement in ASOS



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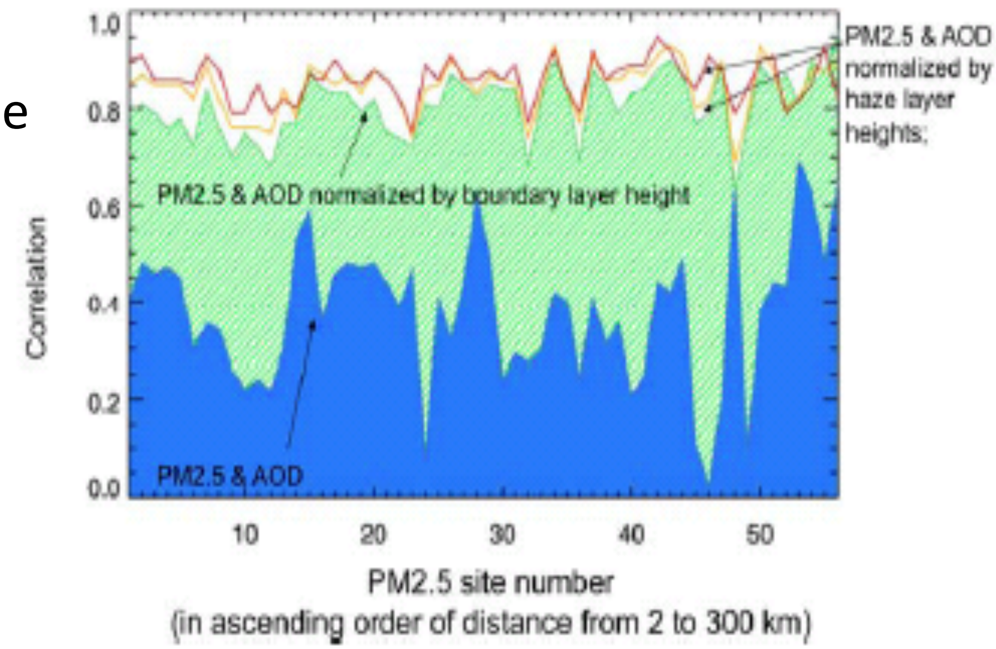
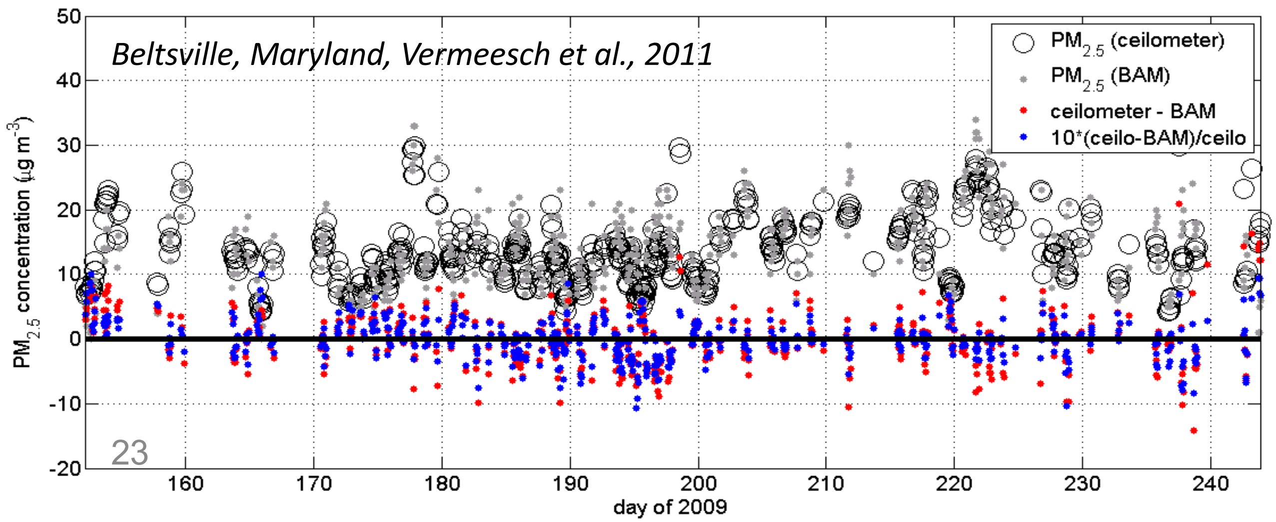
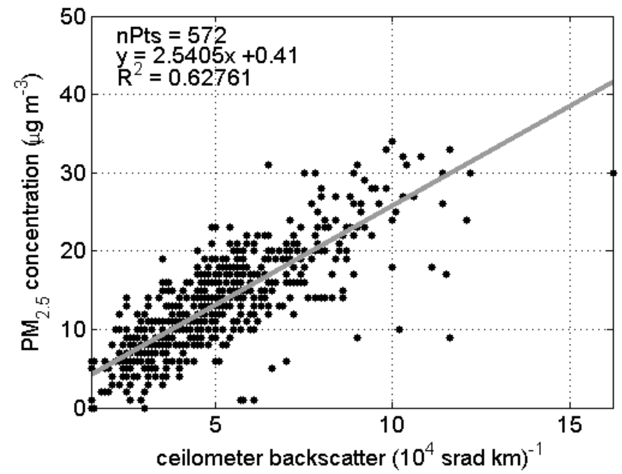
Possible ASOS use in AQ

- First 1-2 signal returns in the CL-31 profile can be used to infer PM loading. Clear sky, RH<62% used[Munkel et al. (2007): Vermeesch et al. (2011), others]



- “Correct and scale” satellite optical depth measurements for AQ studies [*Chu et al., 2013 - DISCOVER-AQ site;]*
  - *Li et al. 2016 used CT25 at Beltsville*



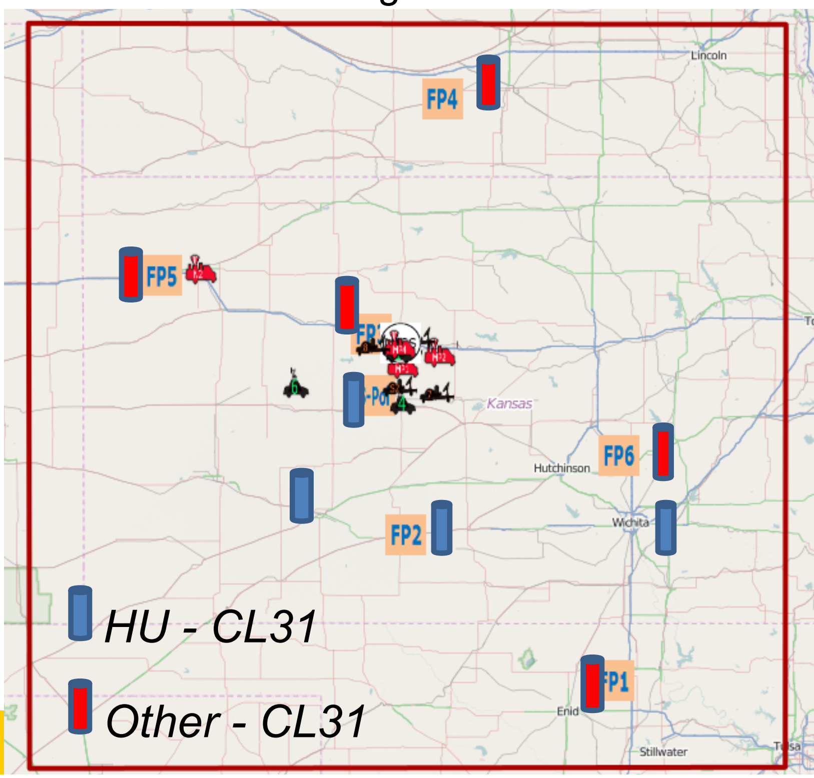


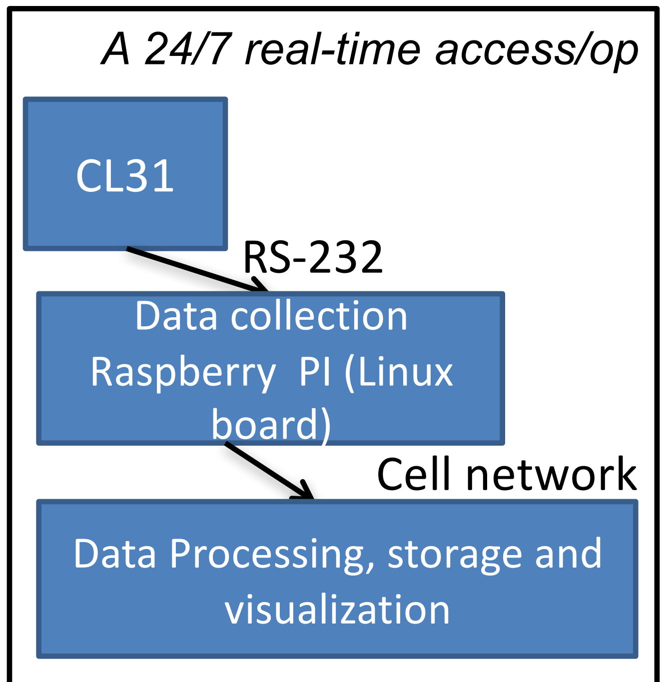
PECAN: *CL31 Network Demonstration for Severe Storm Research*

- **P**lains **E**levated **C**onvection **A**t **N**ight http://catalog.eol.ucar.edu/pecan

A multi-agency, multi-university field observation over Kansas to investigate the sources of nightime summer ***elevated*** convection.

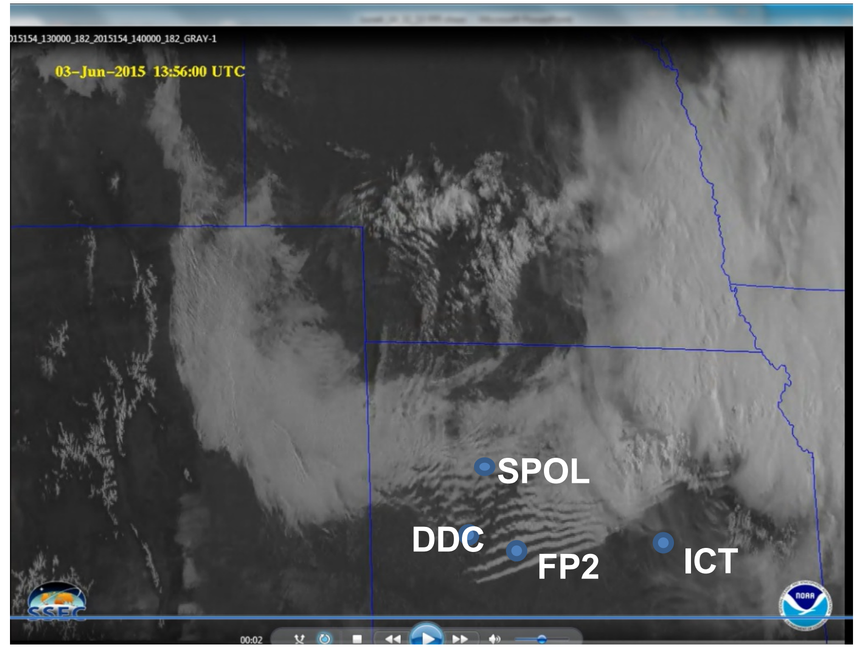
- CL31 (4) were used for realtime network demonstration (see figure below)
- NWS SOO and field sites from Dodge City and Wichita, Kansas were collaborators and allowed siting of two of the CL31s.
- Data collection algorithm and electronics developed and tested.





PECAN: *3 June 2015 Bore Case*

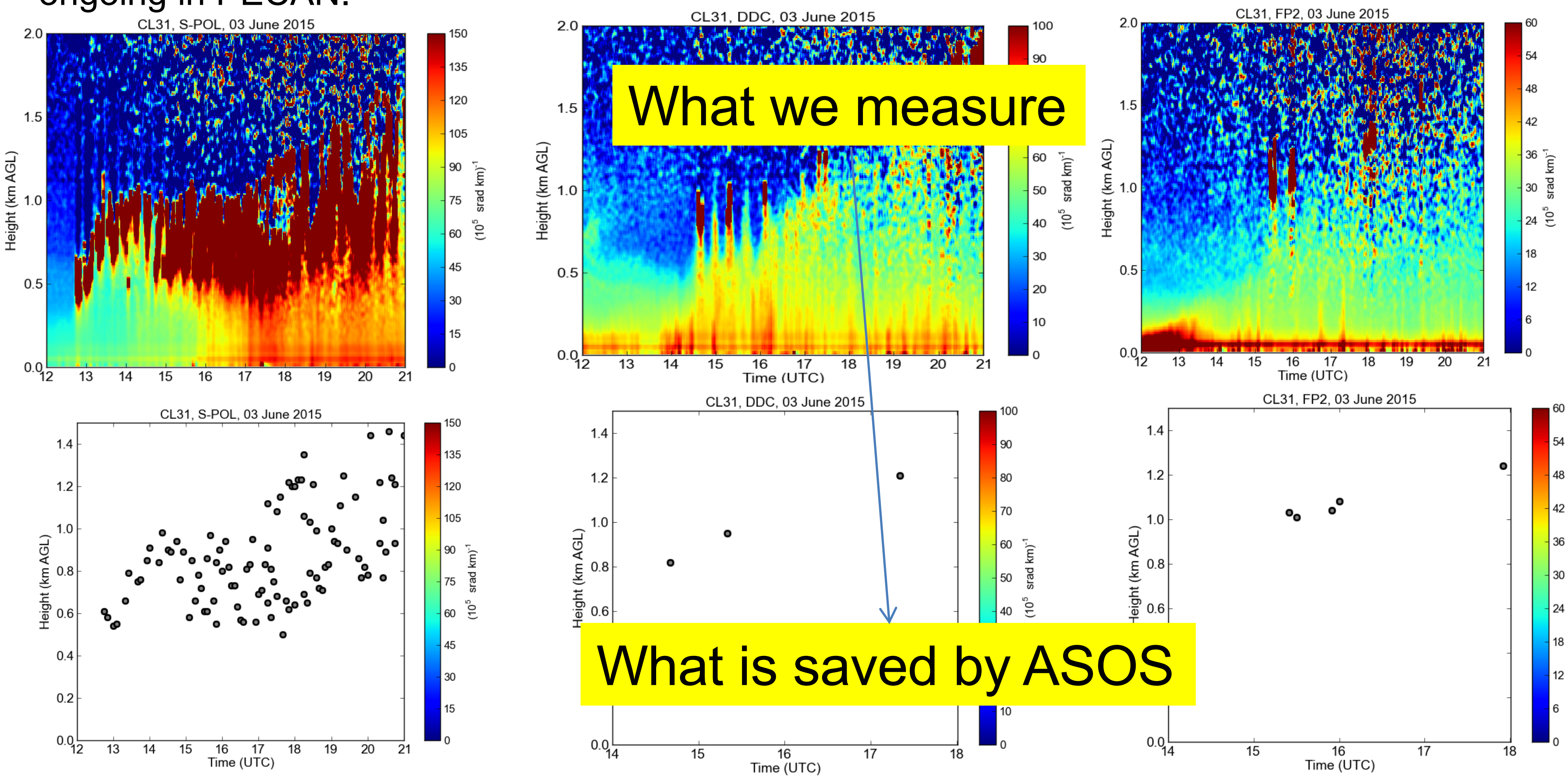

Pictures taken at FP2



- Undular Bores are one of the suspected event that transport moisture upward priming the nightime atmosphere for destabilization and severe storms.
- An accurate statistics of occurrence and observation is lacking, hence PECAN. This is bore case observed early on 3 June 2015, during PECAN.
- The CL31 network reveals the spatial evolution and duration of this bore.

PECAN: *3 June 2015 Bore Case*

CL31 network data from PECAN – no operational instrument is capable of capturing this event in such detail. Equivalent ASOS data is plotted, showing data lost. Analysis of these data sets is ongoing in PECAN.



ASOS project Milestones and Future

Completed

- CL31 PBL Proof of Concept completed
- Management approval to proceed
- Data collection from ASOS demonstrated
- Case Studies Completed
  - PBL, PECAN, Fire etc, (severe storm) – demonstration network completed

In Progress

- More case study/data analysis
- Working on WMO Volcanic Ash expert team
- BAMS paper in draft

Future

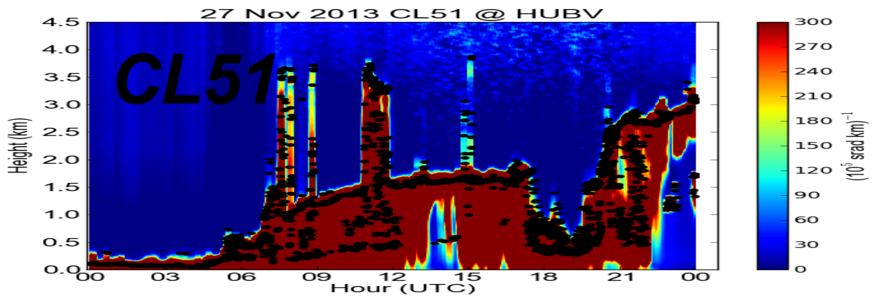
- Algorithm Assessment/Testing in ASOS Operational Environment Complete (planned December 2017)
- Algorithm Incorporated into ASOS* (planned June 2018)
  * dependent upon ASOS ACU/DCP upgrade completion

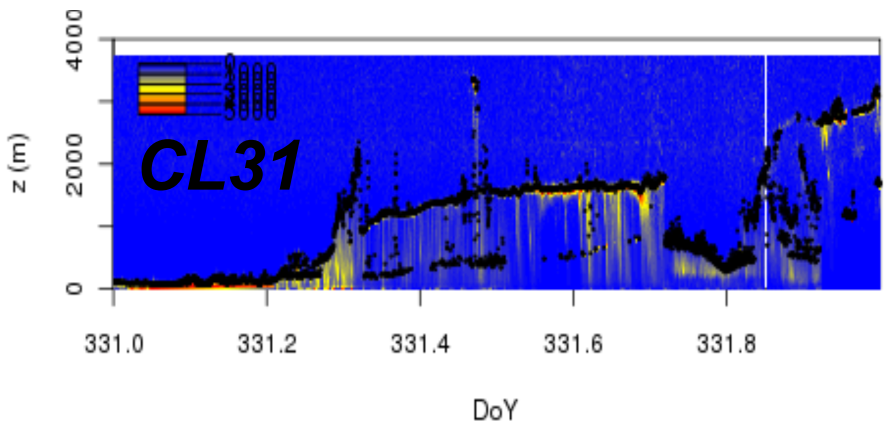
End of Presentation

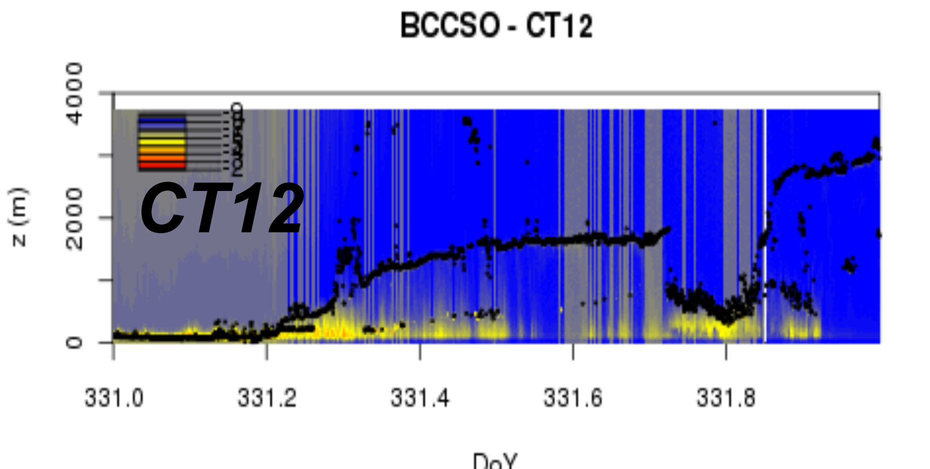
Thank you!

Extra

Instrument types: CL31, CT12K, CL51







Current instrument in test

- Lufft: CHM15K (UMBC, HU)
- Vaisala: CL51, CL31, CT12K

Other Lidars:

- HU-Raman Lidar
- ALVICE (NASA Raman)

Plan to work with MPLnet (J. Welton on PBL and such)

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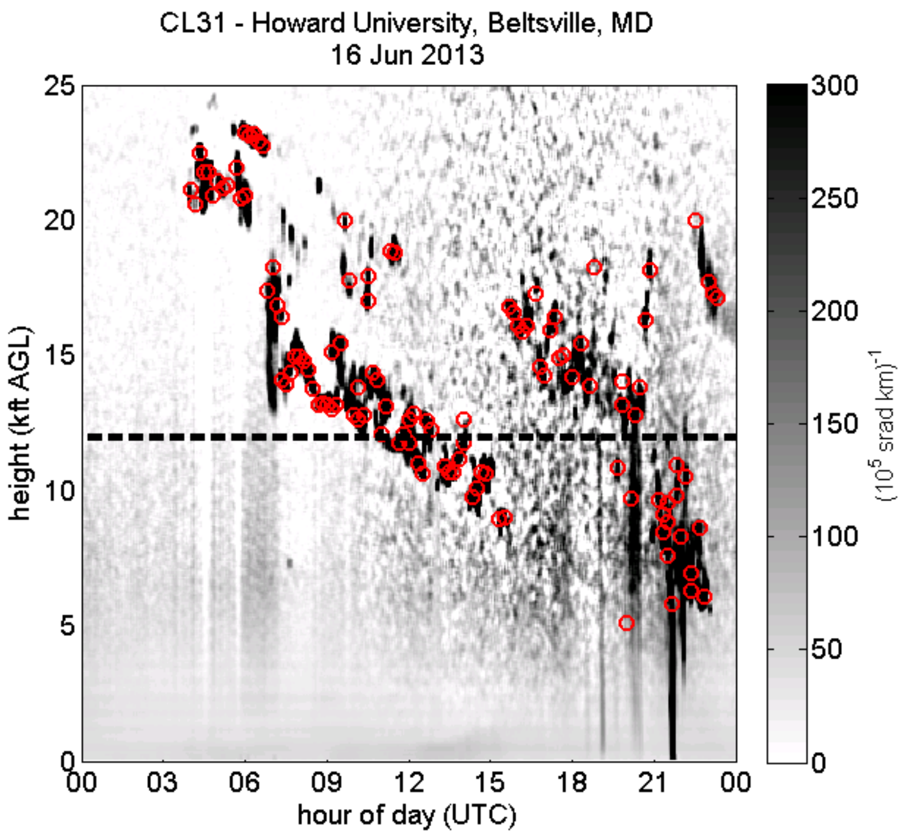
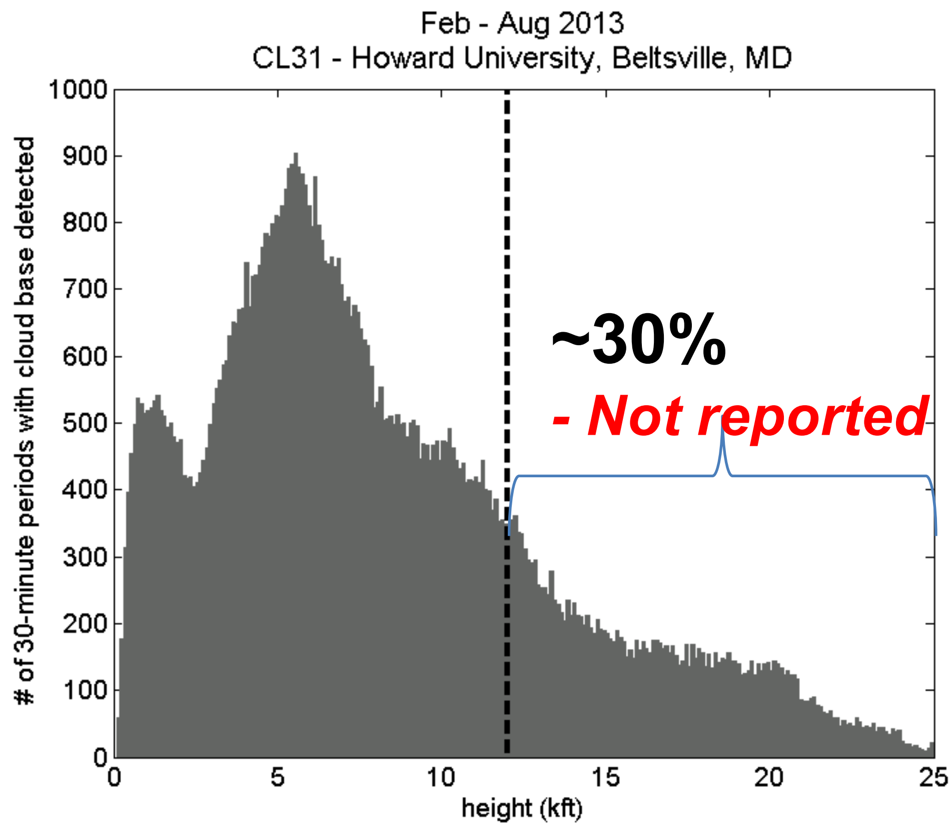
Cloud Statistics @ 12K ft+

- CL31 data statistics:
  - Cloud height statistics above 12K ft needs to be reported





BACK

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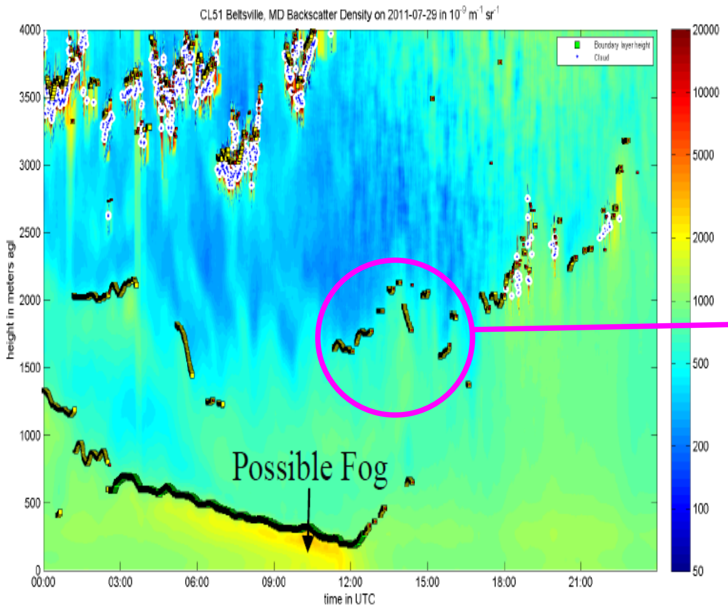
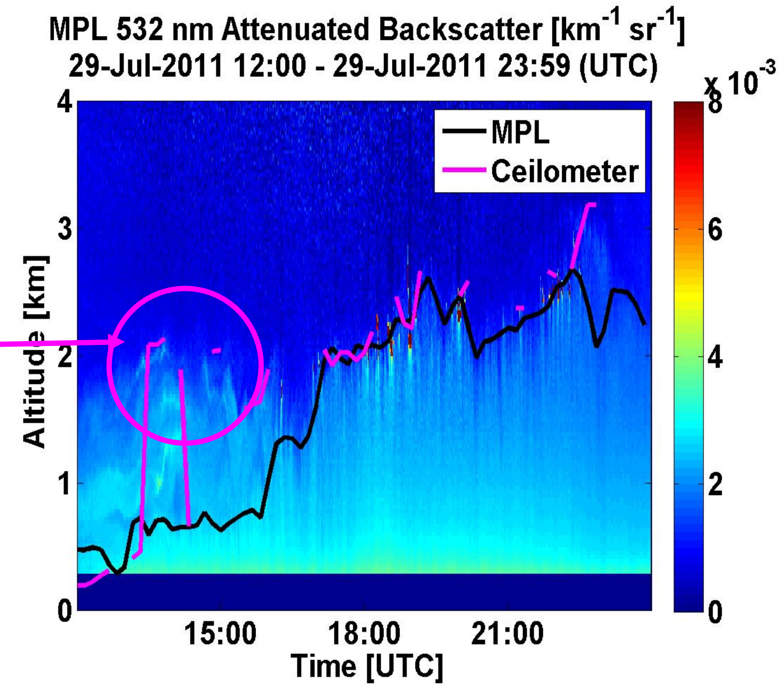
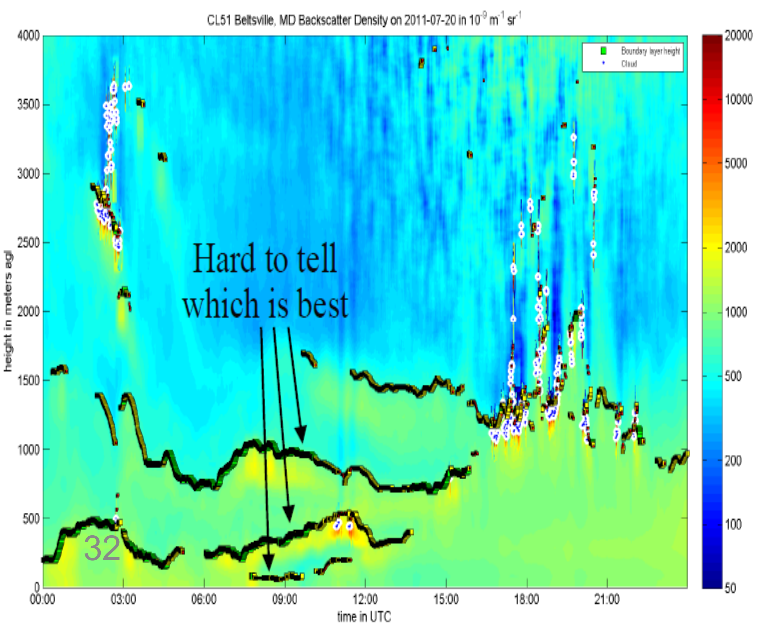


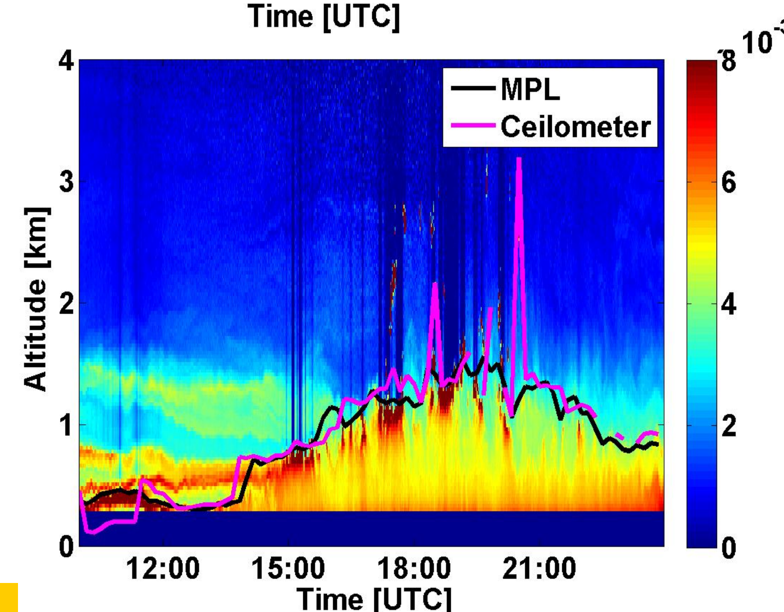
Bad Comparison Day:
Note PBLH missing after 1200 UTC.

Selection criteria for comparison?



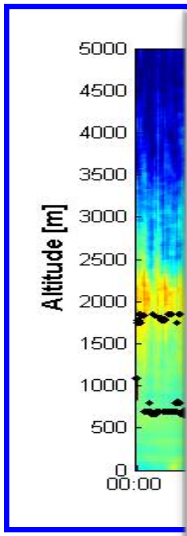


Good Comparison Day:
Success in multiple layers with QI of 3.

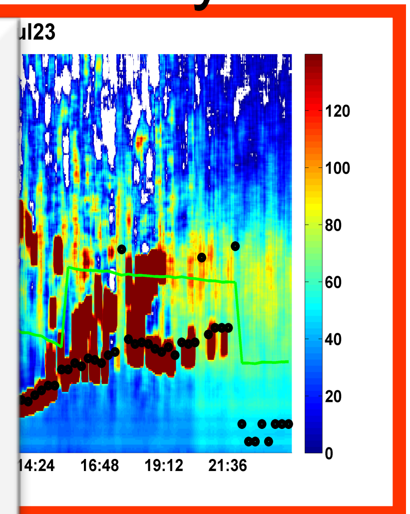


PBL (LCL as filer)

"Bad Day"



"Good Day"



Good PBL Comparison Day:

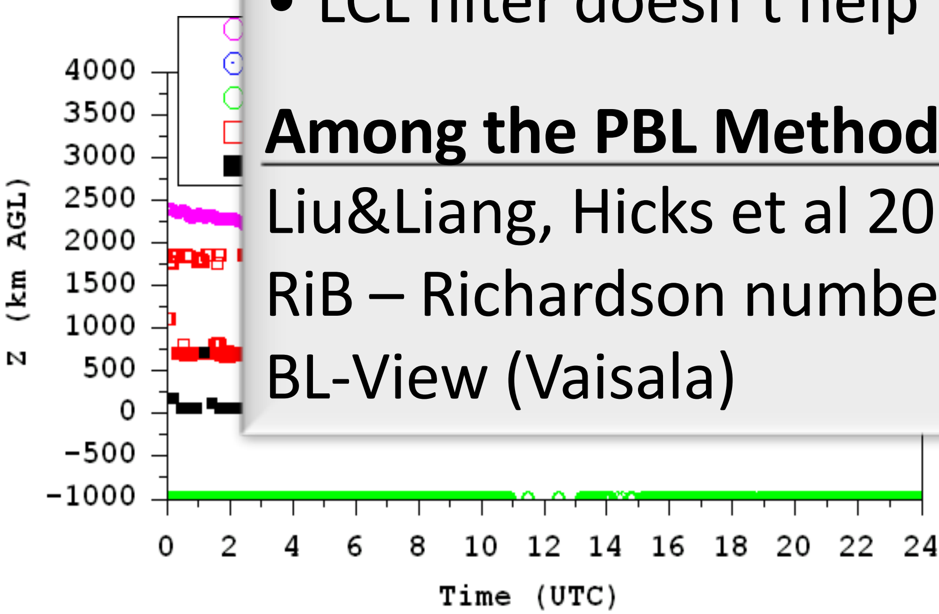
- Excellent morning PBL evolution
- LCL filter *removes day-night transitions issues*

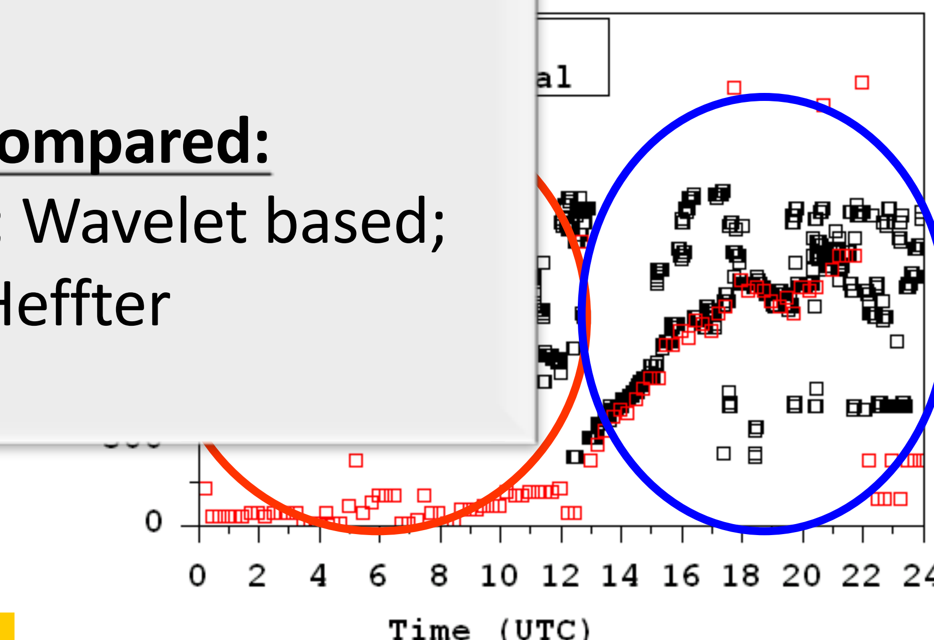
Bad day Comparison Day:

- PBL – definition issue
- LCL filter doesn't help

Among the PBL Methods compared:

Liu&Liang, Hicks et al 2015; Wavelet based; RiB – Richardson number, Heffter BL-View (Vaisala)





Summary: CL31 comparison table

Routine	Pros	Cons	Comments
Hicks	•Good for morning PBL •LCL filter helpful in pruning • NWS origin	•Day-Night trans a challenge •LCL filter removes elevated NBL	***Published in BLM Hicks et al., 2015;*** *Combines some of the error-function , Meteorology, and can run on archive.*
UMBC	•Performance as Hicks et al.; •Compared to radar-SNR •Compared to others	• Day-Night trans a challenge	***Published in Compton et al.,****2013. local source and similar to Hicks et al. Also used by MDE etc.*
BL-View	• Runs in real time now • well tested/robust (NWS Seattle, Vancouver, EU, etc) • designed for the ceilometer	•1-software to 1-instrument • Not network capable • limits the profile to 4.5km	Several papers. Commercial backing. Costly, in relative terms, unless negotiated.

Recommendation:

- ***A combination of UMBC/Hicks methods be used on current data.***
- ***A low-cost, network capable, commercial software is desirable.***
- ***Ability to processes real-time as well as archive data is desired.***

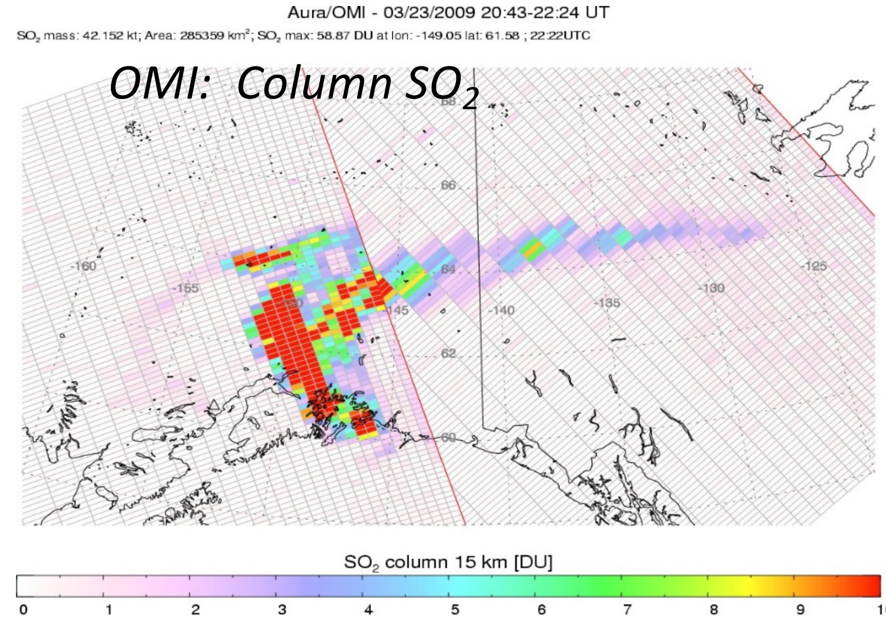
Redoubt – *Plume of March 23, 2009*

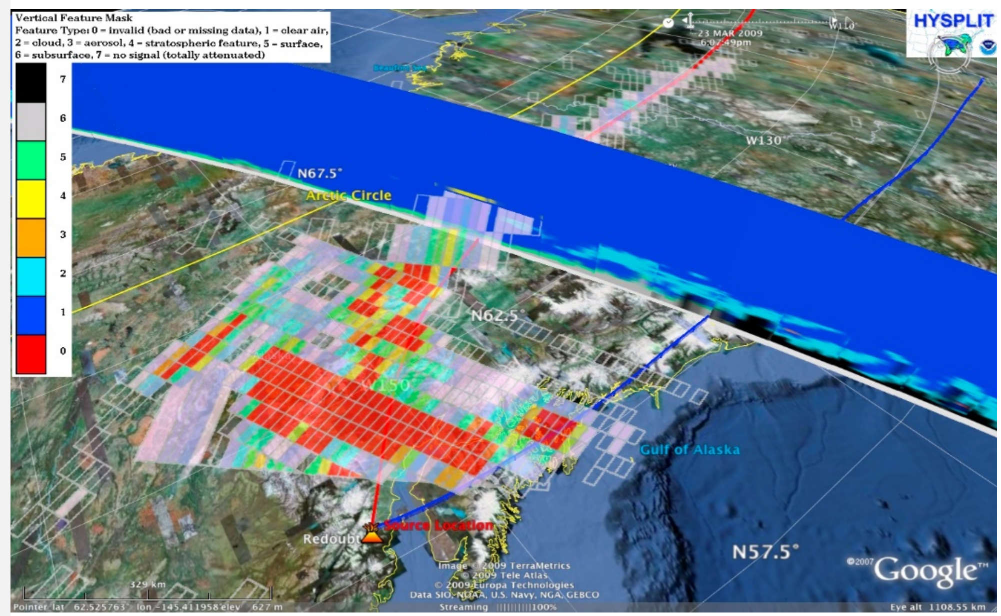
How could ASOS have helped in Volcanic ash studies?

Could the CL31 have seen the ash?

<u>Steps used:</u>

- *OMI/CALIPSO for plume boundary*
- *Estimate aerosol "loading" above background.*
- *Locate if within CL31 range*
- ***Speculate*** *if it would have been detected and measured.*





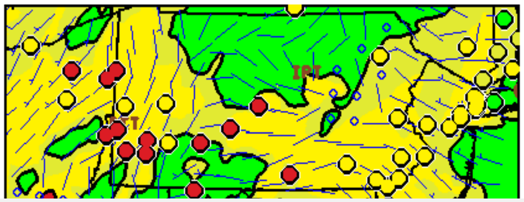
http://so2.gsfc.nasa.gov/pix/special/2009/redoubt/redoubt_all.html

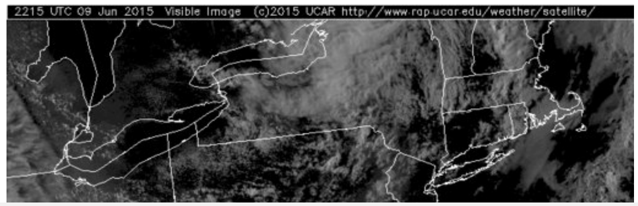
UMBC

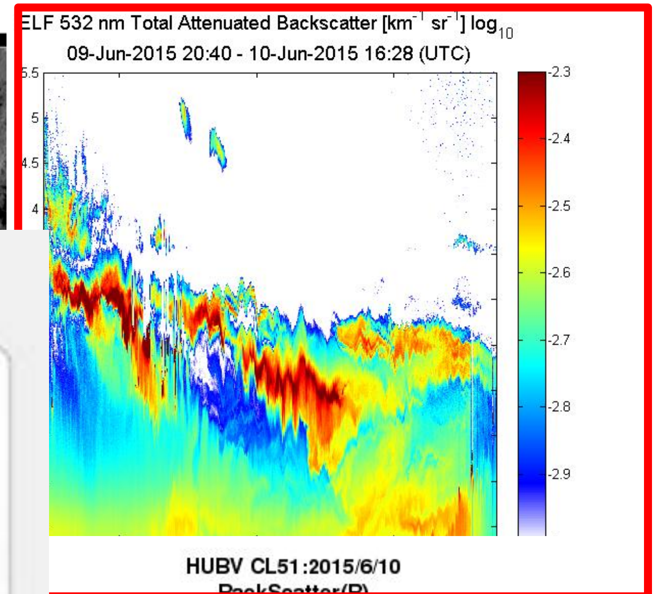
AN HONORS UNIVERSITY IN MARYLAND

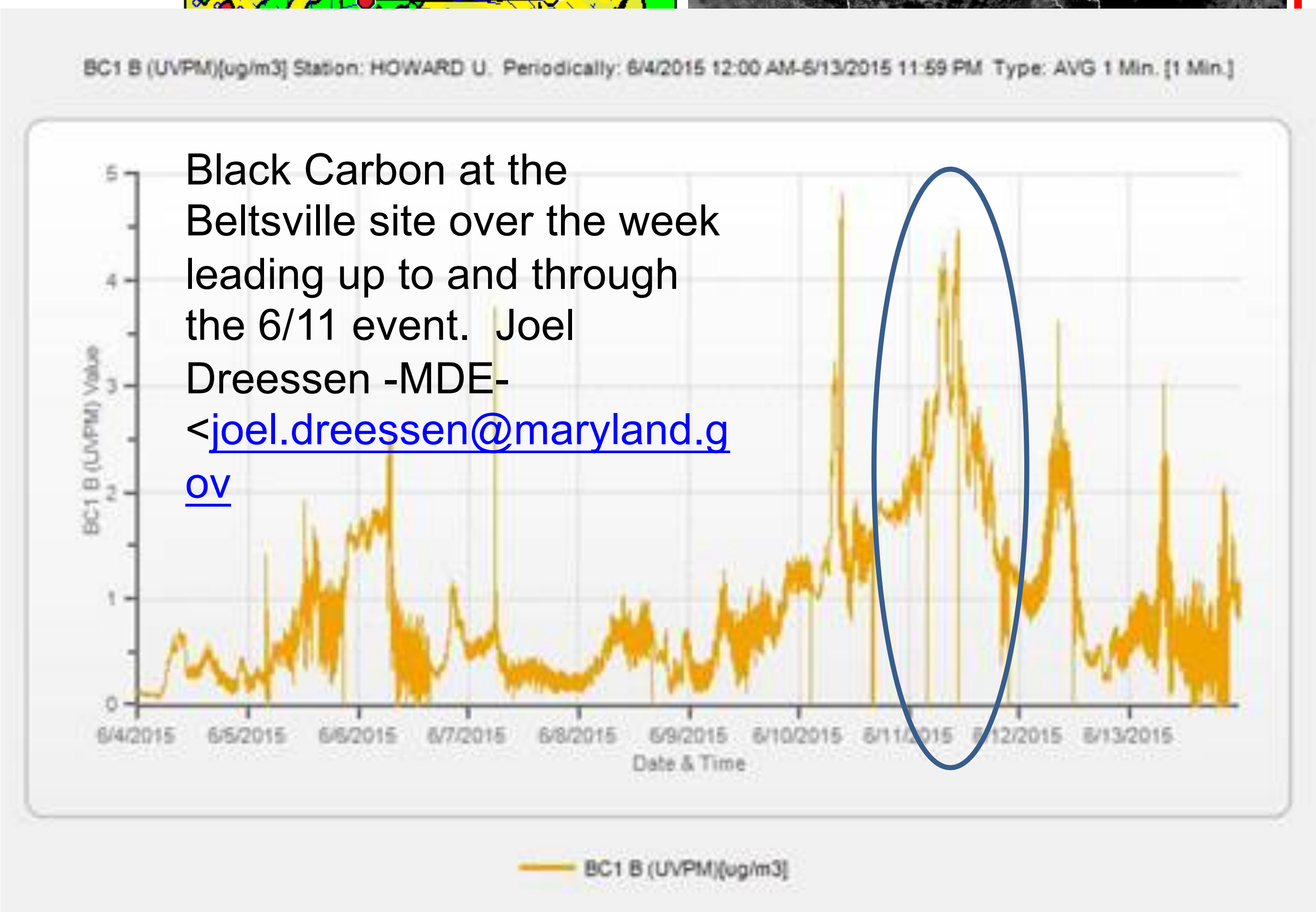
CL31: Fire and Smoke pollution

http://alg.umbc.edu/usaq/

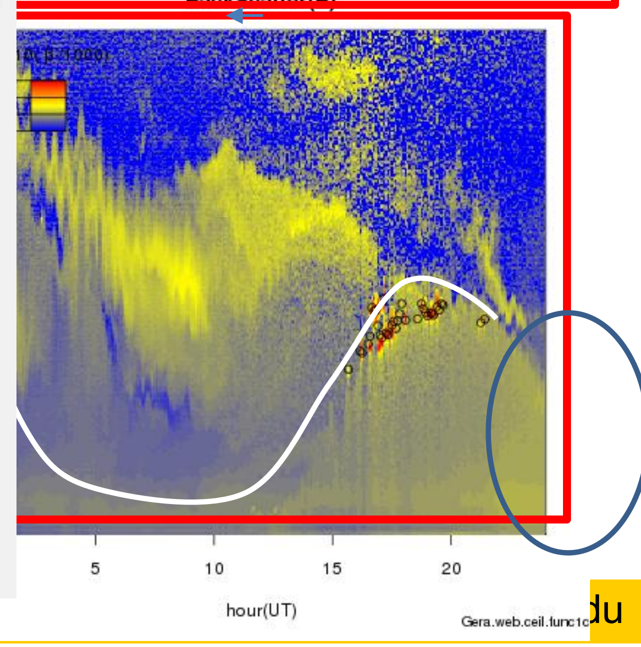








Black Carbon at the Beltsville site over the week leading up to and through the 6/11 event. Joel Dreessen -MDE- <joel.dreessen@maryland.gov

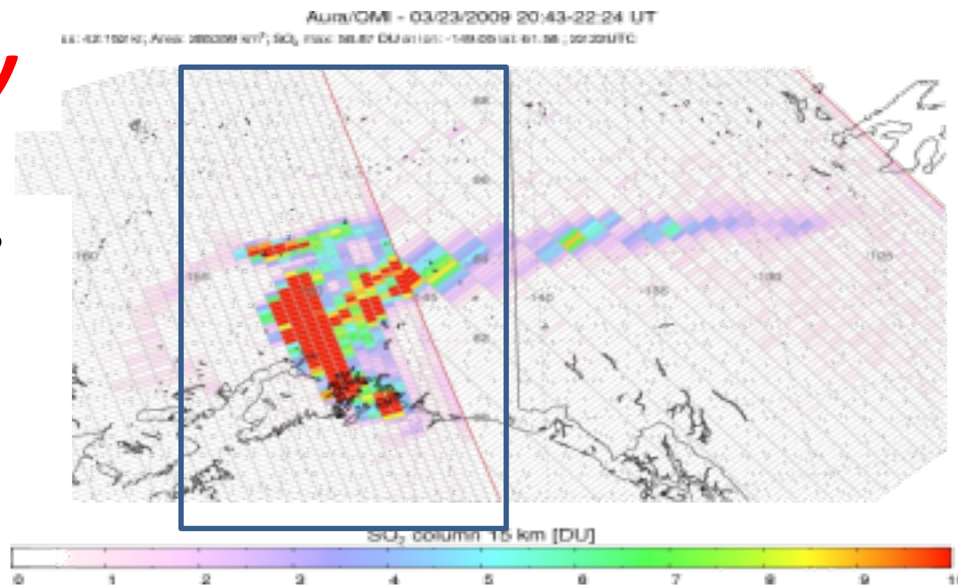


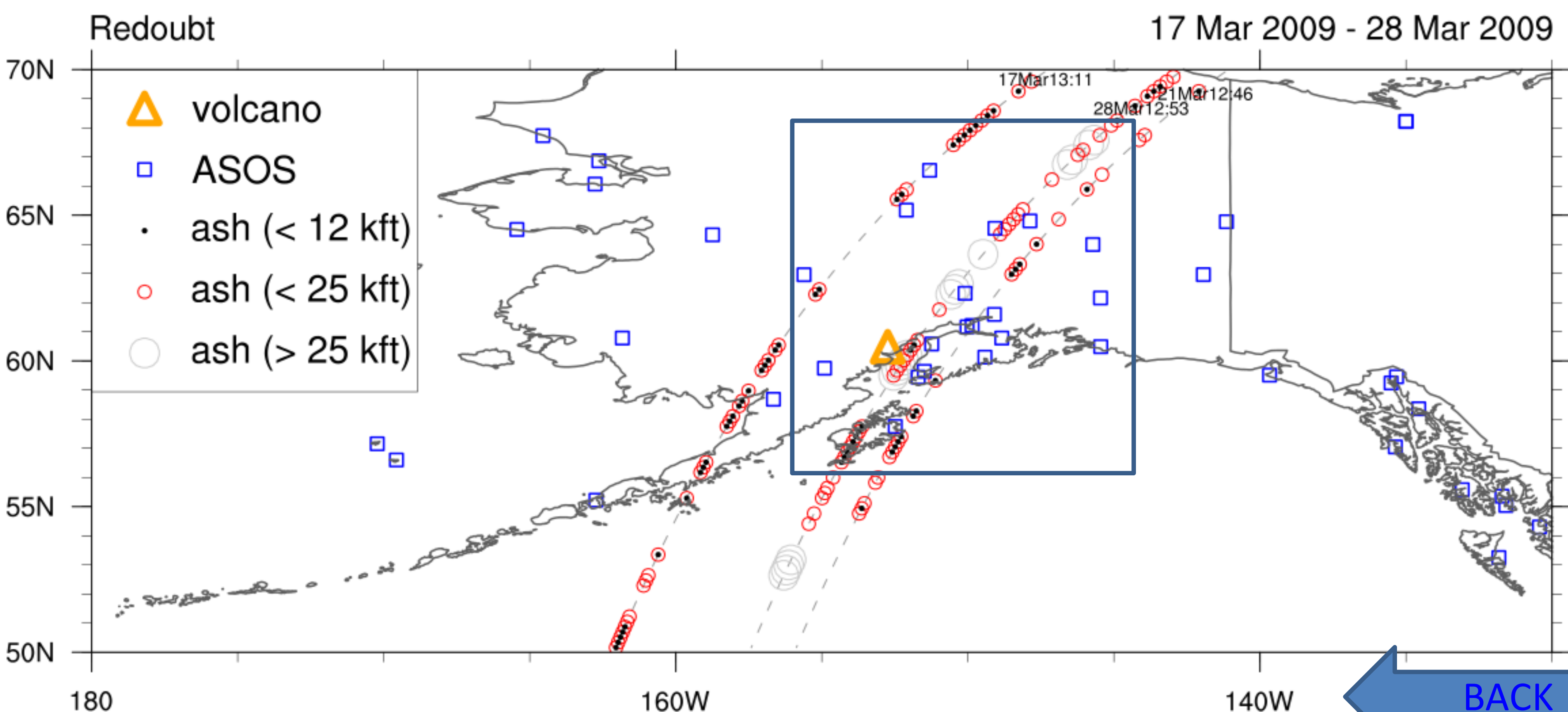
hour(UT)

du

Redoubt: *Lost opportunity*

- *Plume of 03/23/2009 would have been detected by ASOS lidars*
- *Would have assisted NWS-Alaska region in monitoring.*

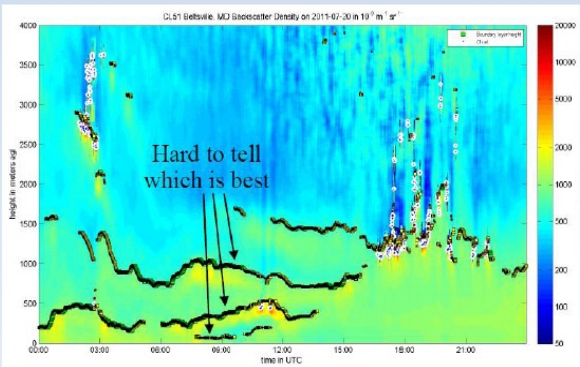


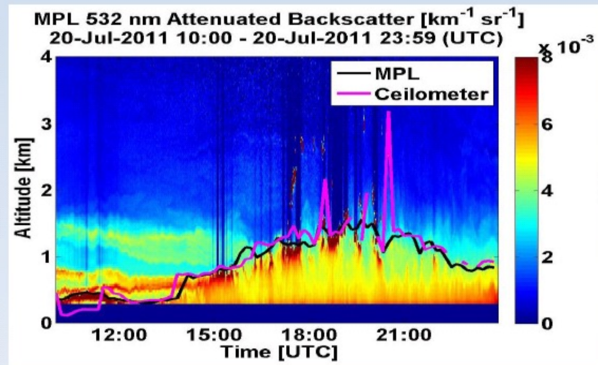


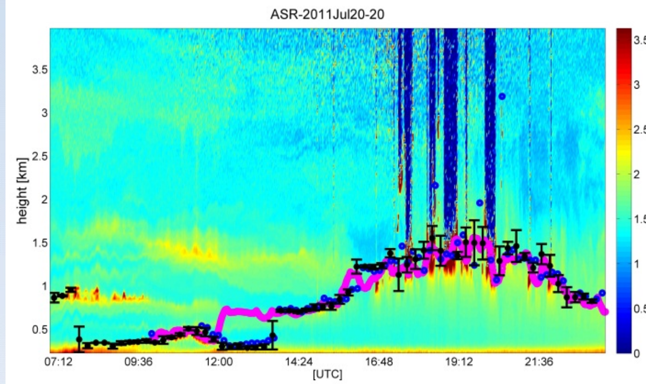
BACK

Algorithm Comparison

DISCOVER AQ Summer 2011 @ Beltsville, MD



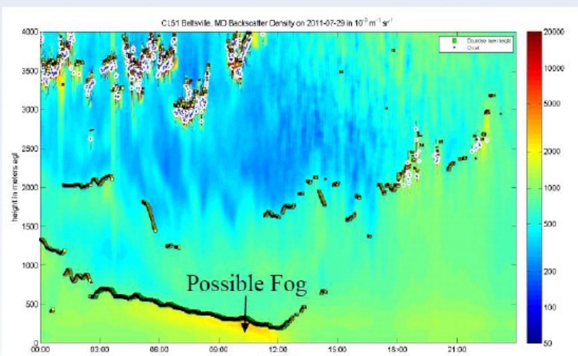


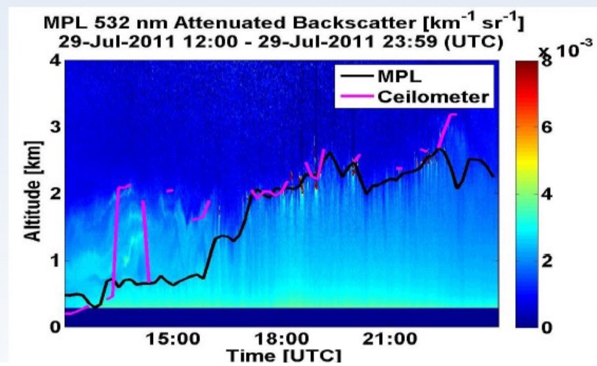


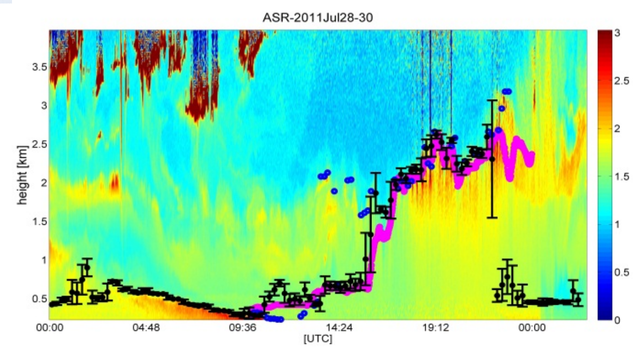
CL51 Ceilometer

MicroPulse Lidar (MPL)

Howard Raman Lidar







Laser: InGaAs
Power: 8.9 mW
Wavelength: 910 nm
Algorithm: BL-View

Laser: Nd-YLF
Power: 25 mW
Wavelength: 532 nm
Algorithm: Wavelet

Laser: Nd-YAG
Power: 8 W
Wavelength: 355 nm
Algorithm: Wavelet

CL31 PBL Review

Summary:

		BLView avg diff (m)	Hicks avg diff(m)
	Method		
STABLE	Liu Liang	710.327	12.066
	RiB	770.776	173.336
	Heffter	761.597	54.004
	AVERAGE	768.476	123.15
CONVECTIVE	Liu Liang	196.37	-604.388
	RiB	527.195	-175.566
	Heffter	-299.849	-1151.683
	AVERAGE	227.076	-732.185

Lidar-sonde differences:

- BL-View data close to the sonde is chosen from the 3-choices.
- UMBC/Hicks lowest reported is chosen
- ***Explore smarter method for comparing algorithms***

NB: PBLH comparisons under ideal conditions – revealed +/- 200m (IHOP2002)

Peak-based Threshold

The MLH is defined as the highest point connected to the ground in the profile

$$\tau_p = \min\left(0.9\,\sigma_w^B + 0.1\,\sigma_w{}^p\ ,\ \sigma_w^0\right)$$

$$Z_{CtG} = \max\left\{z\ /\ \sigma_w(z) > \tau_{p_{CtG}}\right\}$$