The NASA Micro Pulse Lidar Network (MPLNET): 25 years of collaboration with AERONET

Ellsworth J. Welton*
NASA GSFC

* 30 years of collaboration
- my entire career!

I began working in this field in 1994, at the end of my 1st year of grad school

Grad student in the Physics Department at Univ of Miami

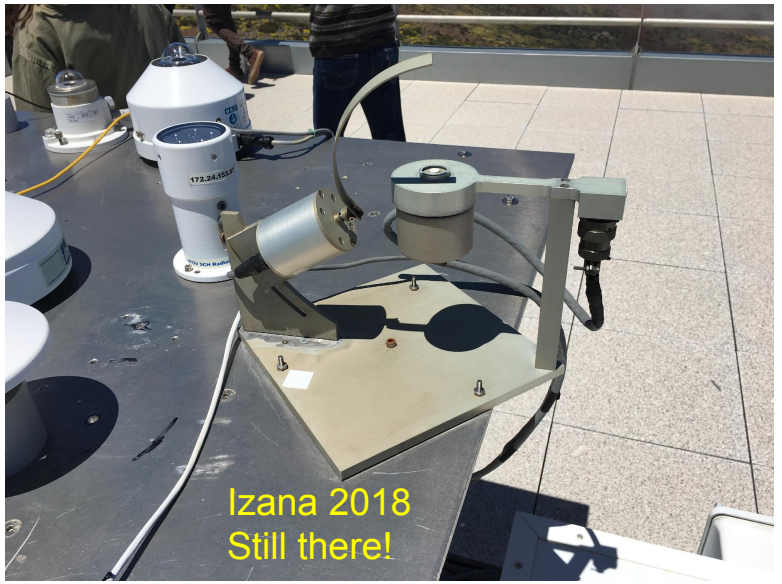
Working with Ken Voss (my PhD advisor) and Howard Gordon (Physics), also with Joe Prospero's aerosol group RSMAS.

Managed hand-held sunphotometers and shadowband radiometers (pre-commercial) in the Aerosol-Ocean-Chemistry Experiment sites: Miami, Bermuda, Barbados

Calibration & processing, retrieved AOD and AE, correlation with in-situ sampling

Later in 1994, they bought a new instrument from a company called Cimel, to work with this new project at NASA. That was added to my task.

Calibrating shadowbands at Izana in summer of 1994

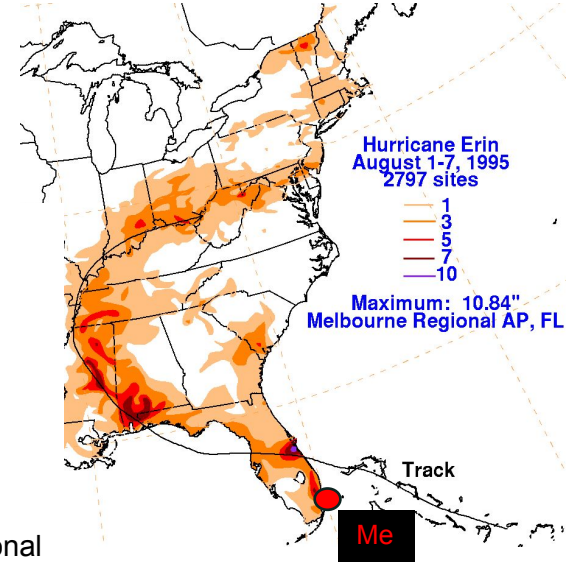


I become an AERONET site operator in 1994

University of Miami – RSMAS Campus
Site: Key_Biscayne
1994 – 1996
1 of 47 total sites at the time

First time I “met” Brent – August 1995

Aug 1: Brent called me at home (somehow)
< 1 day before Hurricane Erin



Brent: “Judd! Its Brent.”
Me: “Who?”
Brent: “Brent Holben, with AERONET”
Me: “How? What …”
Brent: “Ya, there’s a hurricane coming at you”
Me: “I know, the entire city is freaking out …”
Brent: “Did you take the cimel down at Key Biscayne?”
Me: “Ah, no. The island is being evacuated”
Brent: “Well you really should take it down”
Me: “Uh, ok” … but wanting to say something unprofessional

I become an AERONET site operator in 1994

University of Miami – RSMAS Campus
Site: Key_Biscayne
1994 – 1996
1 of 47 total sites at the time

Fort Jefferson
Dry Tortugas, FL
Site: Dry_Tortugas
1996 - 1998

The Micro Pulse Lidar – 1996

Micro Pulse Lidar (MPL) developed at GSFC in the early 1990s, including funding from ARM. Four prototypes were delivered to ARM and installed at their sites.

The MPL was patented and commercialized.
Science and Engineering Services Inc (SESI) first company.

Our group bought the first commercial MPL ~1996
Serial number 0005 (they included the 4 prototypes)

I was tasked with the MPL:
Testing, calibration, processing, deployments
Ocean color validation cruises to MOBY in Hawaii

I began interacting with the MPL team at NASA around this time.

I could not find a good pic of the original MPL. This is a similar era model at our GSFC site in early 2000s.

We built an environmental housing for the MPL, which was used throughout my grad school and post-doc.

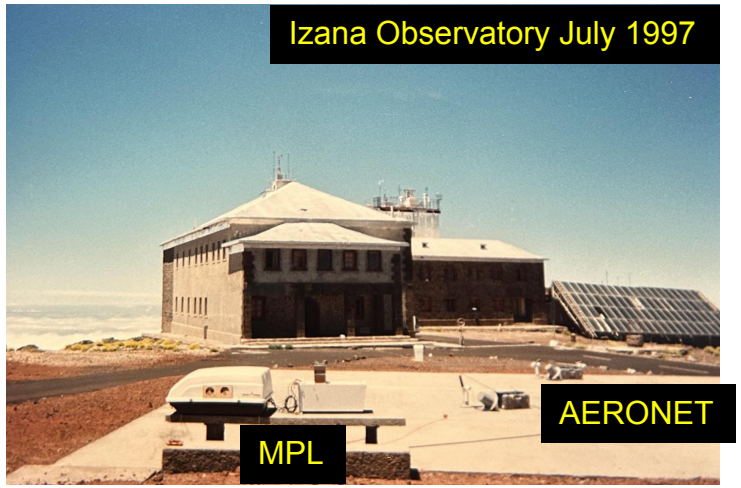
NOTE: the MPL and newer miniMPL are now sold by Droplet Measurement Technologies

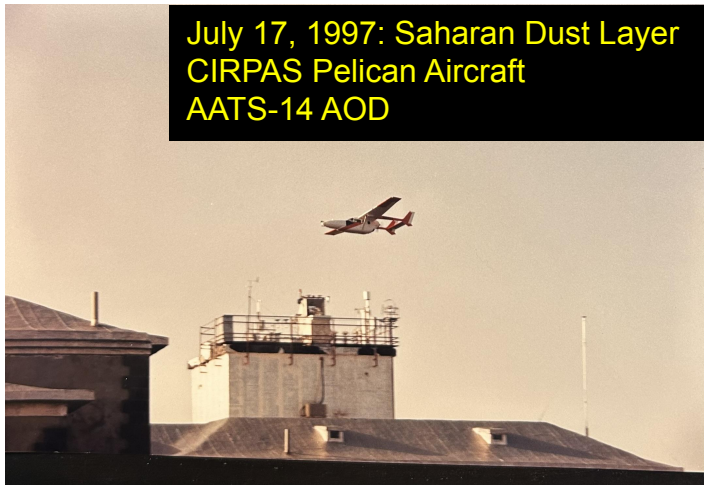
The Aerosol Characterization Experiment 2 (ACE-2) - 1997

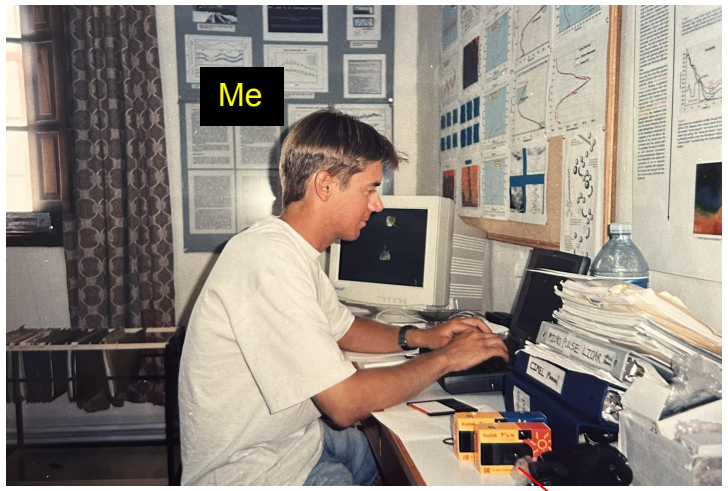
I went back to Tenerife and Izana for ACE-2

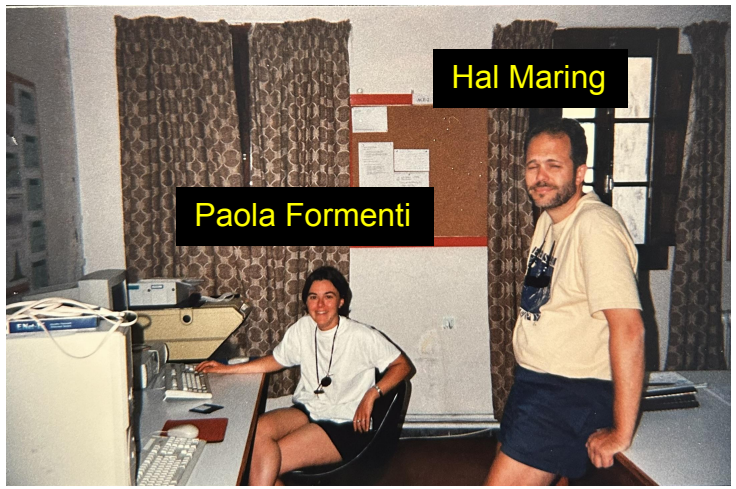
I deployed the MPL and 2 AERONET sunphotometers to measure aerosol properties

This included joint work with AERONET (Smirnov), the NASA AATS team (Schmid), and MPI team (Formenti). The analysis of a dust layer on July 17 was the first time we had validation of an MPL aerosol retrieval!



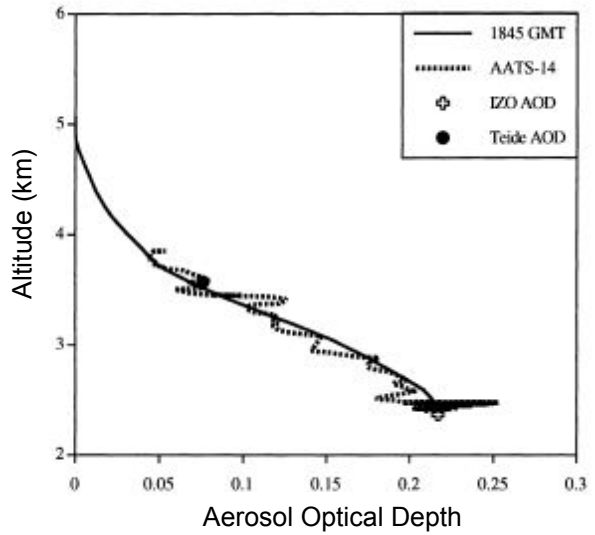






This was pre-digital, before you could tell someone their eyes are closed!

July 17, 1997 Dust Layer



Welton et al, 2000

The Indian Ocean Experiment (INDOEX) - 1999

I graduated with my PhD in 1998

I did a one year post-doc at Univ of Miami, including participating in the Aerosols-99 cruise and INDOEX 1999.

Our Miami team deployed the MPL and a microtops aboard the NOAA R/V Ron Brown for the Aerosols-99 cruise across the Atlantic, continuing onto INDOEX from Cape Town into the Indian Ocean.

I was on the INDOEX portion of the cruise.

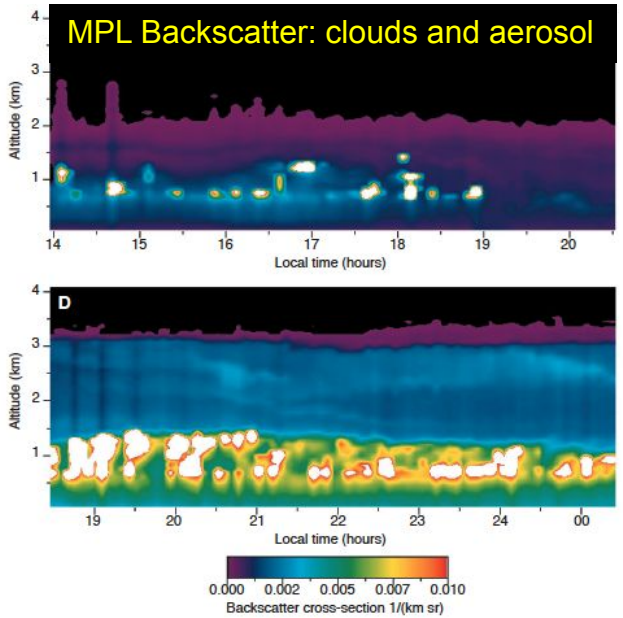
Three significant things happened:

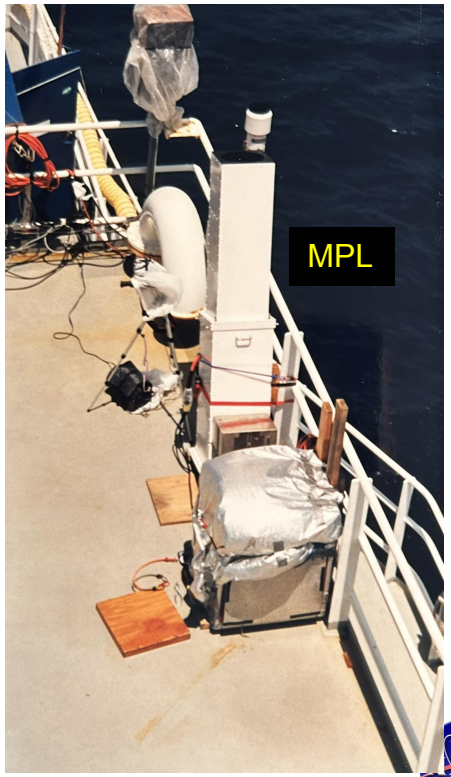
I became a shellback on this cruise

I published a paper and was co-author on a few.
One of them has done a bit better

I accepted a new job at NASA during the cruise.
Based on my experience with AERONET and the MPL I was going to help start what became MPLNET.

Ackerman, A. S., O. B. Toon, D. E. Stevens, A. J. Heymsfield, V. Ramanathan, and E. J. Welton, 2000: Reduction of tropical cloudiness by soot. ***Science***, 288, 1042-1047





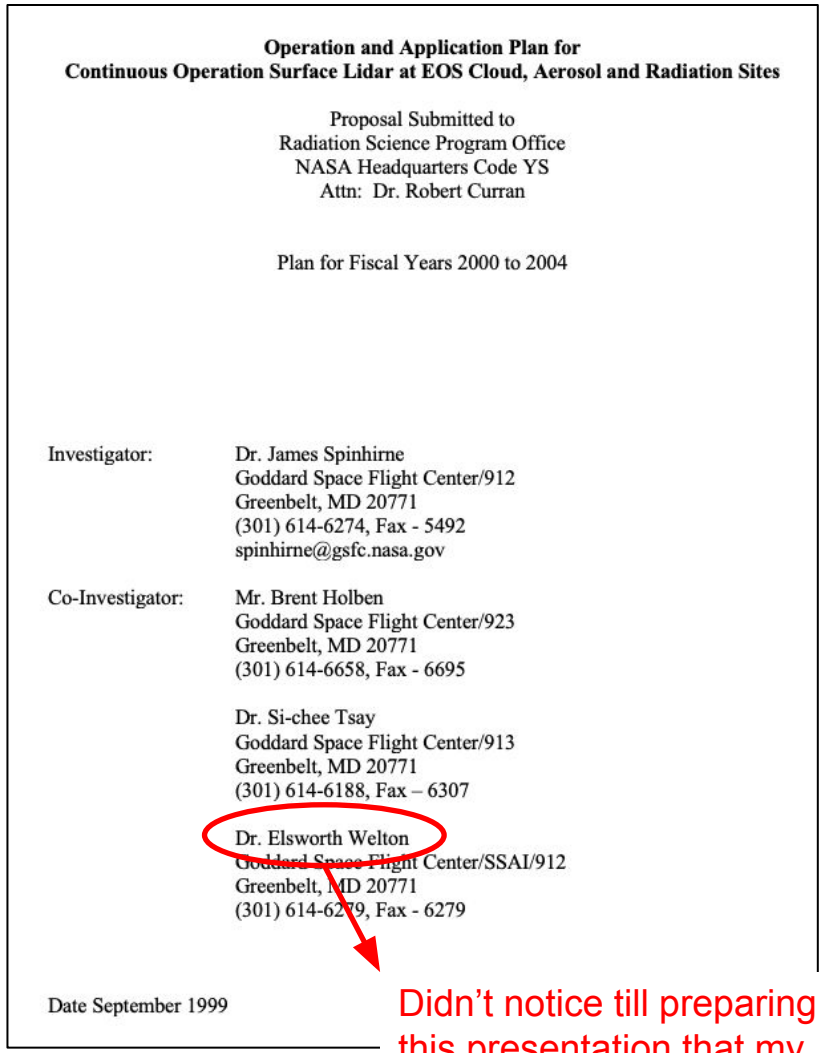
Original MPLNET Proposal Submitted 25 years ago

Original Concept:

Develop a lidar network capable of supporting AERONET column observations

Lidar must be:
- eye-safe
- capable of automated operations
- commercially available (growth)
- have proven performance and peer-reviewed publications

The commercial MPL met these requirements based upon successful deployments such as ARM, ACE-2, and INDOEX.



Operation and Application Plan for
Continuous Operation Surface Lidar at EOS Cloud, Aerosol and Radiation Sites

Proposal Submitted to
Radiation Science Program Office
NASA Headquarters Code YS
Attn: Dr. Robert Curran

Plan for Fiscal Years 2000 to 2004

Investigator: Dr. James Spinhirne
Goddard Space Flight Center/912
Greenbelt, MD 20771
(301) 614-6274, Fax - 5492
spinhirne@gsfc.nasa.gov

Co-Investigator: Mr. Brent Holben
Goddard Space Flight Center/923
Greenbelt, MD 20771
(301) 614-6658, Fax - 6695

Dr. Si-chee Tsay
Goddard Space Flight Center/913
Greenbelt, MD 20771
(301) 614-6188, Fax – 6307

Dr. Elsworth Welton
Goddard Space Flight Center/SSAI/912
Greenbelt, MD 20771
(301) 614-6279, Fax - 6279

Date September 1999

Didn't notice till preparing this presentation that my name was misspelled!

Federated Network Approach:

- NASA to install new sites at GSFC, South Pole, Barbados, West Africa, Australia, Maldives, Middle East
- Incorporate existing partners who had purchased MPL systems: ARM and Japanese colleagues
- Reserve one MPL for field campaigns

Centralized, Standardized Data Processing:

Table 1 Data products

MPL 01	Calibrated lidar signal
MPL 02	Cloud presence and heights of boundaries
MPL 03	Height of aerosol layer/layers
MPL 04	Aerosol optical thickness
MPL 05	Aerosol extinction cross section
MPL 06	Thin cloud optical thickness

MPLNET was approved, began ops in 2000:
- PI: Jim Spihine
- Project Scientist: Judd Welton
- Instruments/Processing: James Campbell
- AERONET liaison: Brent Holben
- Field Campaigns: Si-Chee Tsay
- This begins Version 1 era for MPLNET

MPLNET Project Overview: Network & History

Principal Investigator: 2002 - current
Judd Welton, NASA GSFC Code 612

Current MPLNET Staff:
Sebastian Stewart, Aether Embedded/GSFC 612
Jasper Lewis, UMBC GSFC Code 612
James Campbell, Naval Research Lab
Simone Lolli, CNR Italy
Vinay Kayetha, SSAI GSFC Code 612
Lisa Nalborczyk, SSAI GSFC Code 612

All our international network partners

and AERONET

Funding:
NASA Radiation Sciences Program and Earth Observing System, as well as contributions from our many network partner organizations

MPLNET Sites: 2000 - current

MPLNET Website

MPLNET Project Overview: Network & History

MPLNET Sites: 2000 - current

- 85 sites total
- 28 operational, 57 closed, across 28 countries
- 10 more sites in planning
- colocation with AERONET

MPLNET History:

- Three Version Releases
- Version 1 and 2 (2000 – 2021)
- Version 3 (V3) Released in Nov 2021
- Version 2 and 3 data are available on our website

Web of Science Citation Map 2022

over 100 publications
~ 4 – 5 per year on average

MPLNET Sites: 2000 - current

MPLNET Website

MPLNET: Instrumentation & Operations

Instrumentation:

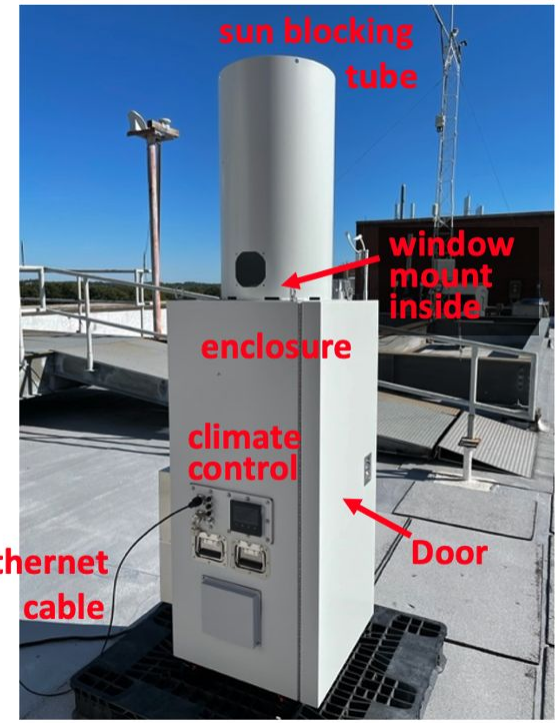
- Micro Pulse Lidar, miniMPL
- Eye safe, green backscatter lidar
- Polarized in early 2000s
- Entire network has polarized MPL since ~2016

Installation Options:
MPLNET provided enclosure or
partner provided lab, trailer, enclosure

miniMPL in mini-enclosure

MPL in Standard Enclosure

Note: the miniMPL also fits in the standard enclosure



Operations:

- Federated Network (NASA + partners)
- Continuous day/night data
- Data resolutions: 1 minute temporal,
  30 or 75 meter vertical, from 0 – 30 km
- Raw data transmitted to central MPLNET server hourly
- Automated processing of data, products available near-real-time (hourly)

MPLNET: Data Product Suite

Modernized Data Product Suite and aligned with AERONET V3

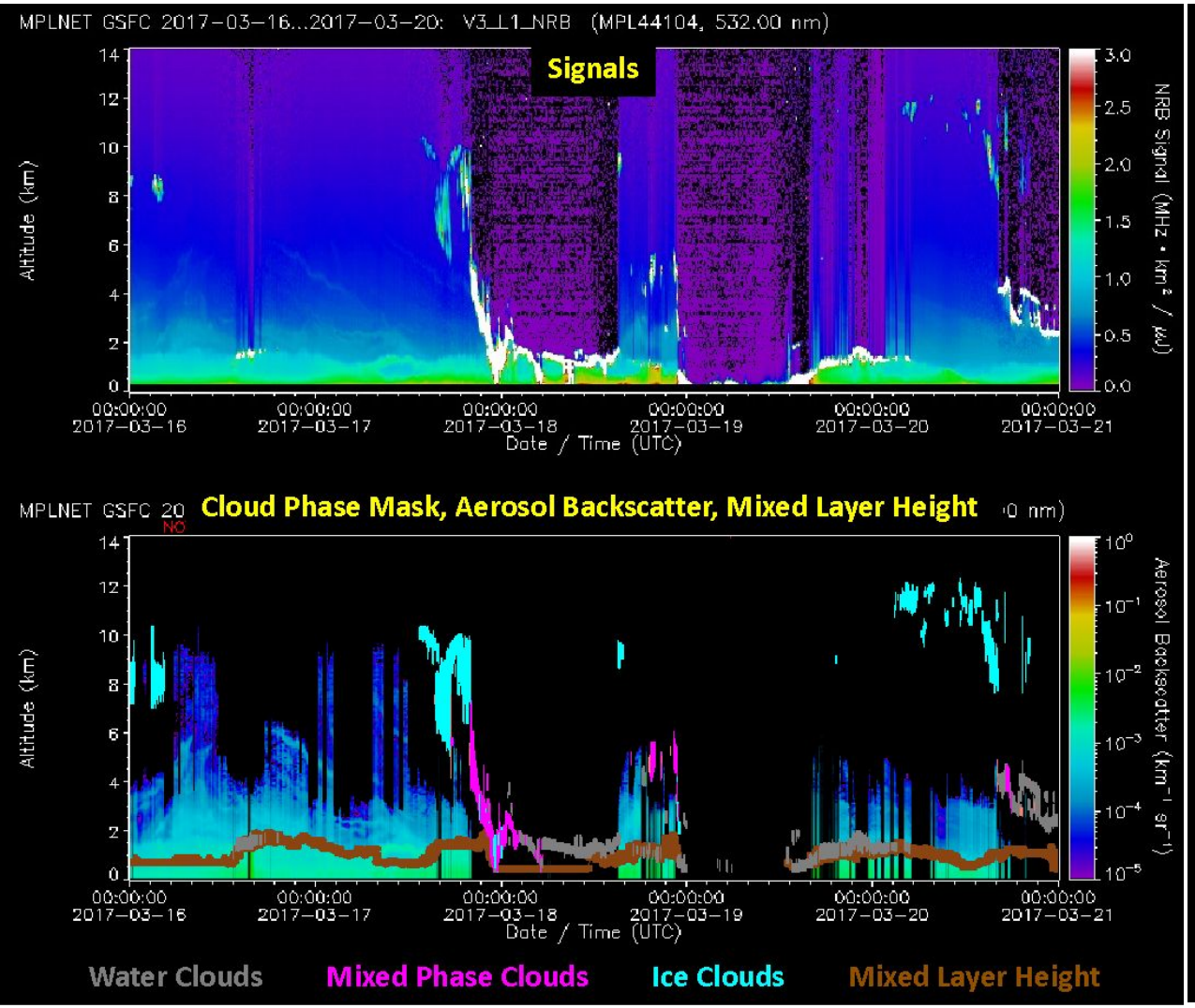
V3 Product	Descriptions
NRB	Lidar signals; volume depolarization ratios; diagnostics
CLD	Cloud heights; thin cloud extinction and optical depths; cloud phase
AER	Aerosol heights; extinction, backscatter, and aerosol depolarization ratio profiles; lidar ratio
PBL	Surface-Attached Mixed Layer Top and estimated AOD
Product File Formats	
Formats	MPLNET V3 products are NETCDF 4, CF compliant files. Subsets for each product may be selected to reduce file sizes.

Product Levels	Availability	Calibration	QA Screen	Ancillary Input
L1_NRB L1_CLD L1_PBL L1_AER	Automated Browse: Near Real Time Download: Next Day *	intial, ongoing field calibrations	none	GEOS5 Forecast NRT, reprocessed next day with GEOS5 Assimilated, AERONET L15 AOD
L15_NRB L15_CLD L15_PBL L15_AER	Automated Browse: Near Real Time Download: Next Day *	intial, ongoing field calibrations	L15	GEOS5 Forecast NRT, reprocessed next day with GEOS5 Assimilated, AERONET L15 AOD
L2_NRB L2_CLD L2_PBL L2_AER	**After post calibration and AERONET L2**	intial, ongoing field calibrations, post calibration, additional‡	L2	GEOS5 Assimilated, AERONET L2 AOD

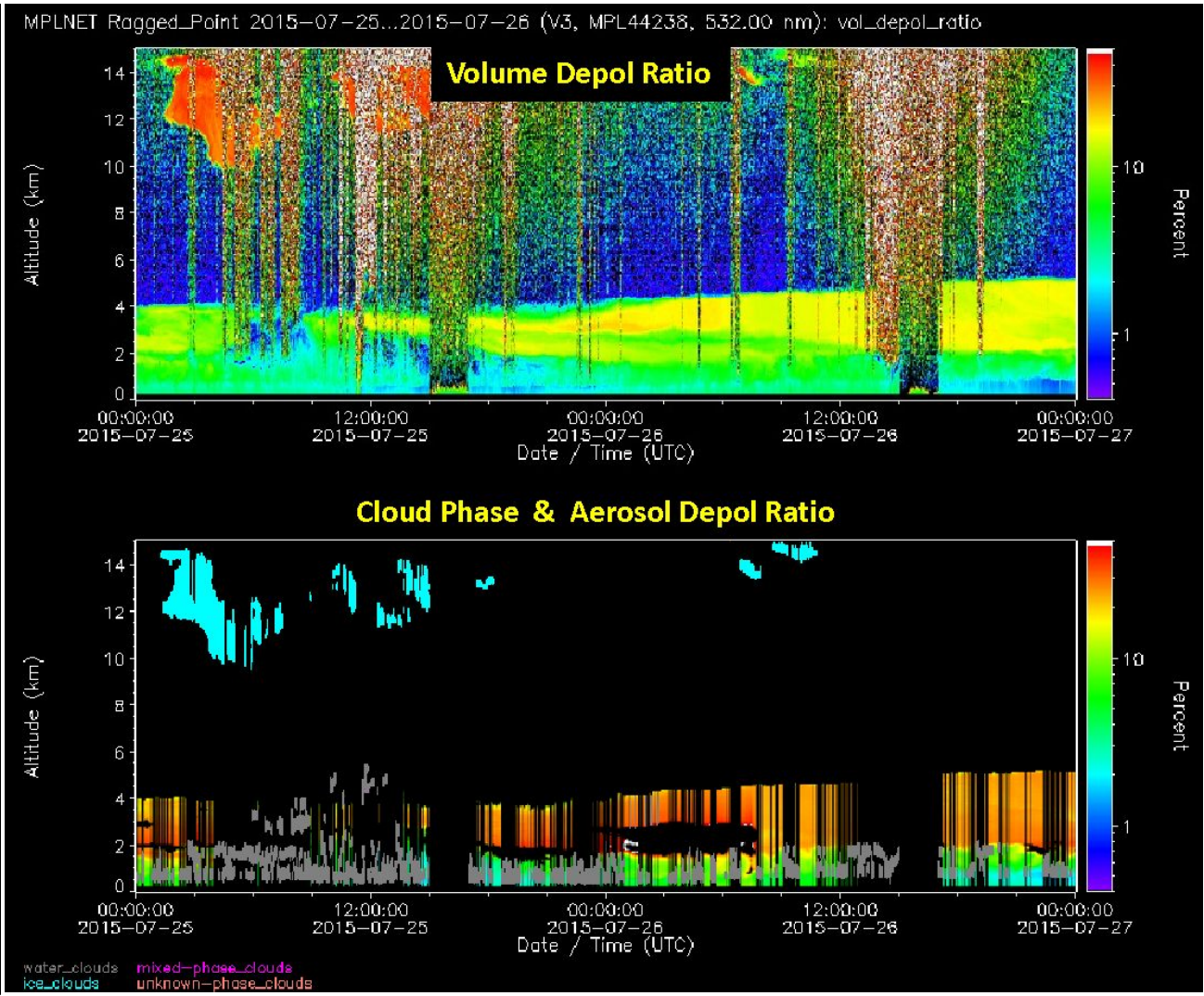
* Near real time data can be provided to site partners and forecasting/modeling centers

MPLNET: Data Product Examples

GSFC, USA: 2017-03-16 to 2017-03-20

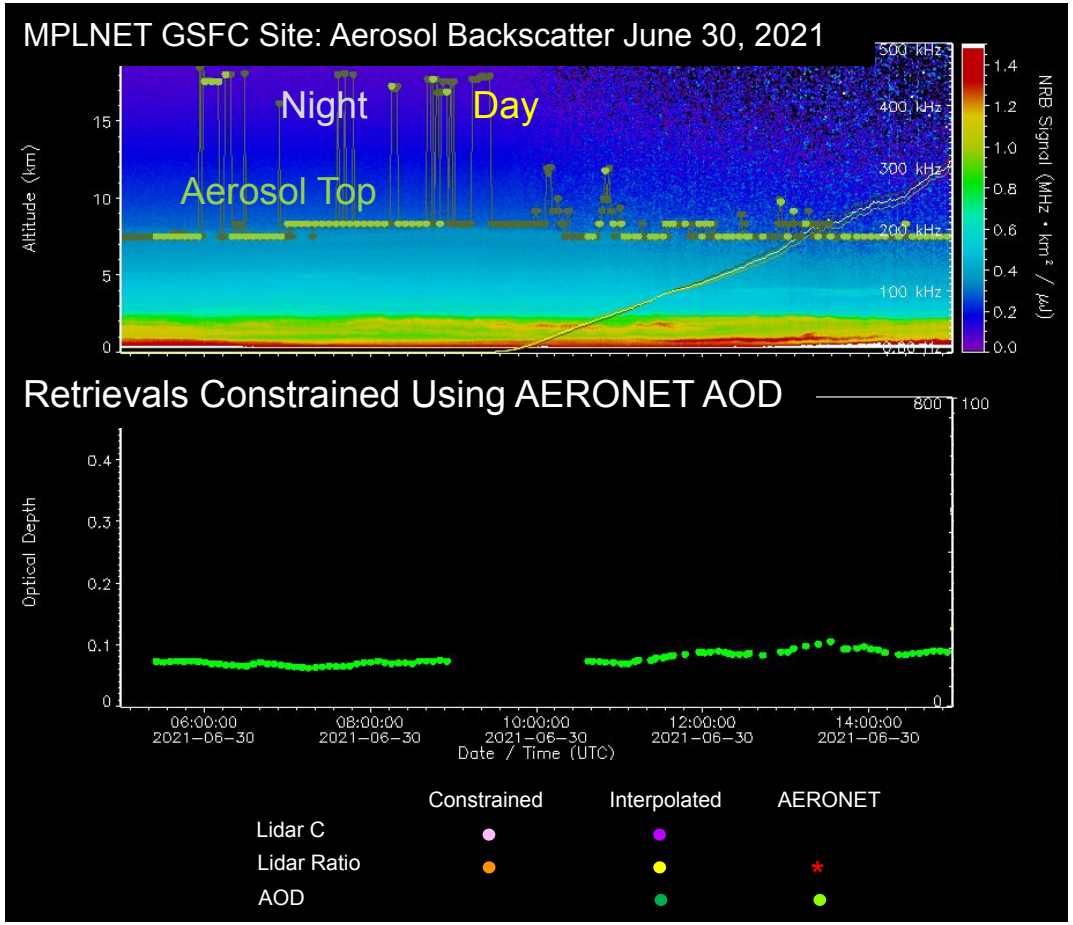


Ragged_Point, Barbados: 2015-07-25 to 2015-07-26



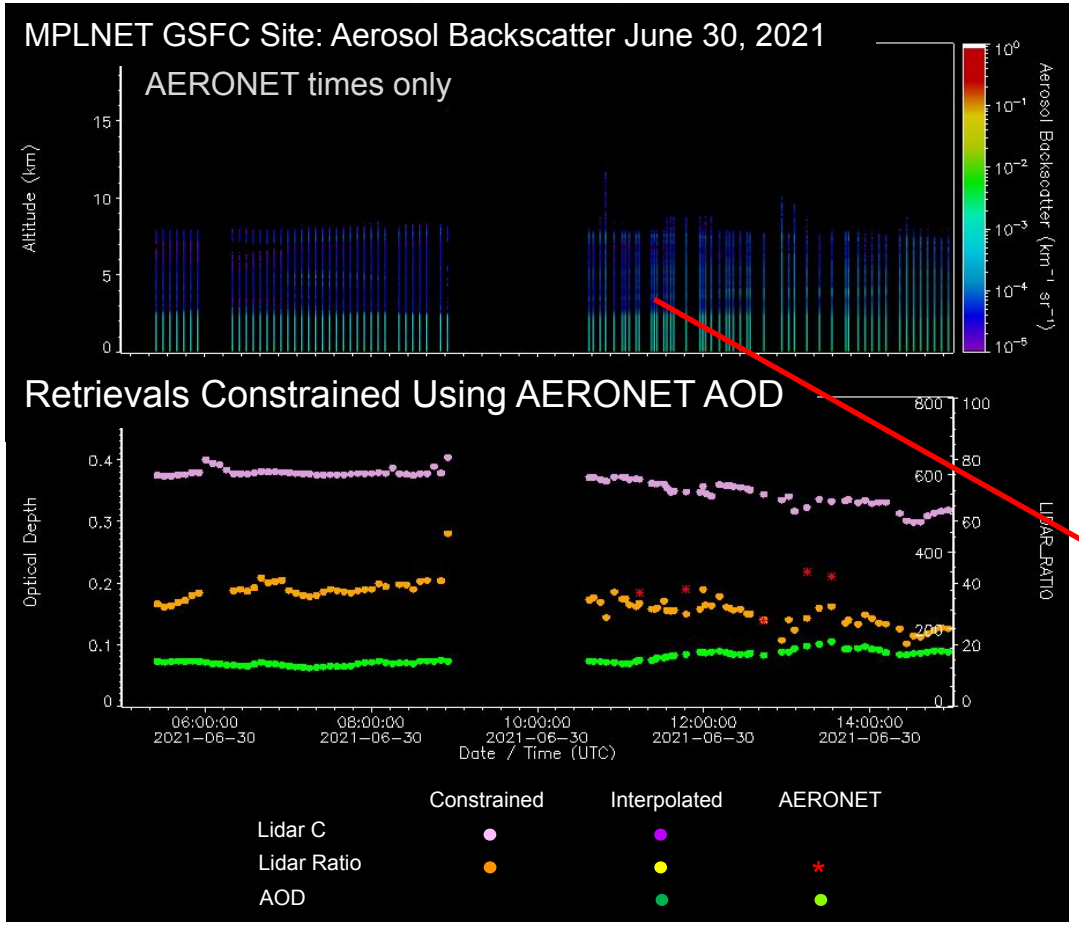
MPLNET: How we utilize AERONET Data

Aerosol properties are retrieved using AERONET



MPLNET: How we utilize AERONET Data

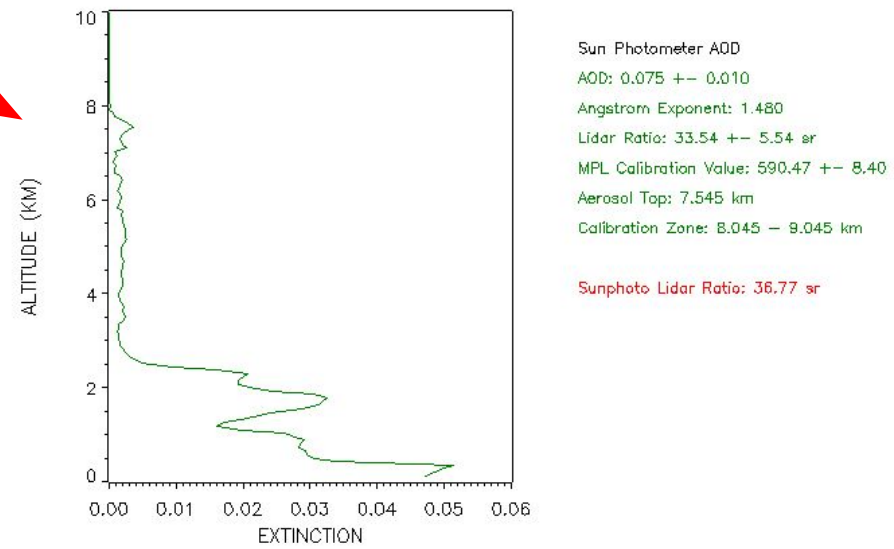
Aerosol properties are retrieved using AERONET



Aerosol retrievals are performed for all AERONET AOD observations

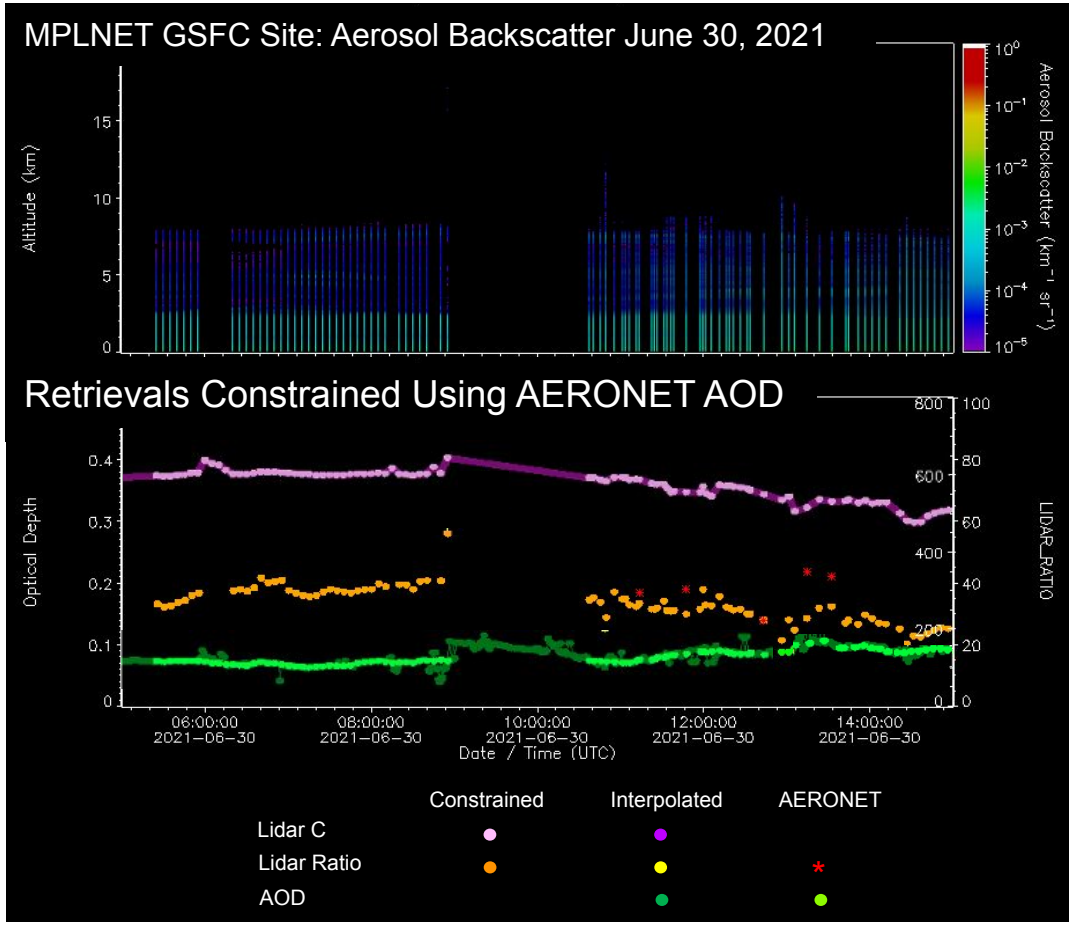
Constrain a Fernald/Klett retrieval by forcing the extinction to integrate to AERONET AOD (Marenco et al 1997, Welton et al 2000).

This method does not require a priori specification of the lidar ratio, it calculates a column average value in the solution.



MPLNET: How we utilize AERONET Data

Aerosol properties are retrieved using AERONET



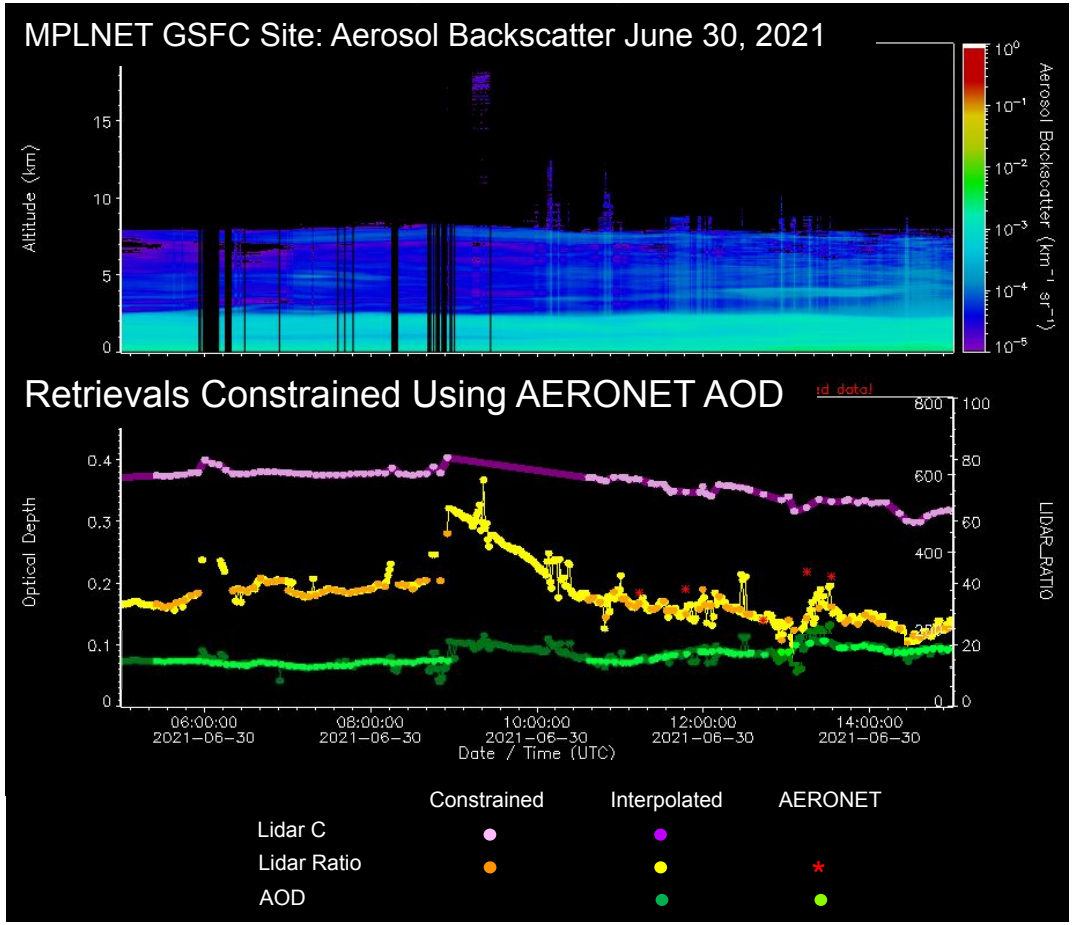
The retrieved lidar constant (C) values are interpolated to the 1 minute temporal grid

These are used to calculate column AOD at times without AERONET observations

$$AOD = \frac{1}{2} ln \left[\frac{C\beta_M(r)}{P_{NRB}(r)} \right] - MOD(0,r)$$

MPLNET: How we utilize AERONET Data

Aerosol properties are retrieved using AERONET



The retrieved C values are interpolated to the 1 minute temporal grid

These are used to calculate column AOD at times without AERONET observations

$$AOD = \frac{1}{2} ln \left[\frac{C\beta_M(r)}{P_{NRB}(r)} \right] - MOD(0,r)$$

The interpolated AOD are used to retrieve aerosol properties

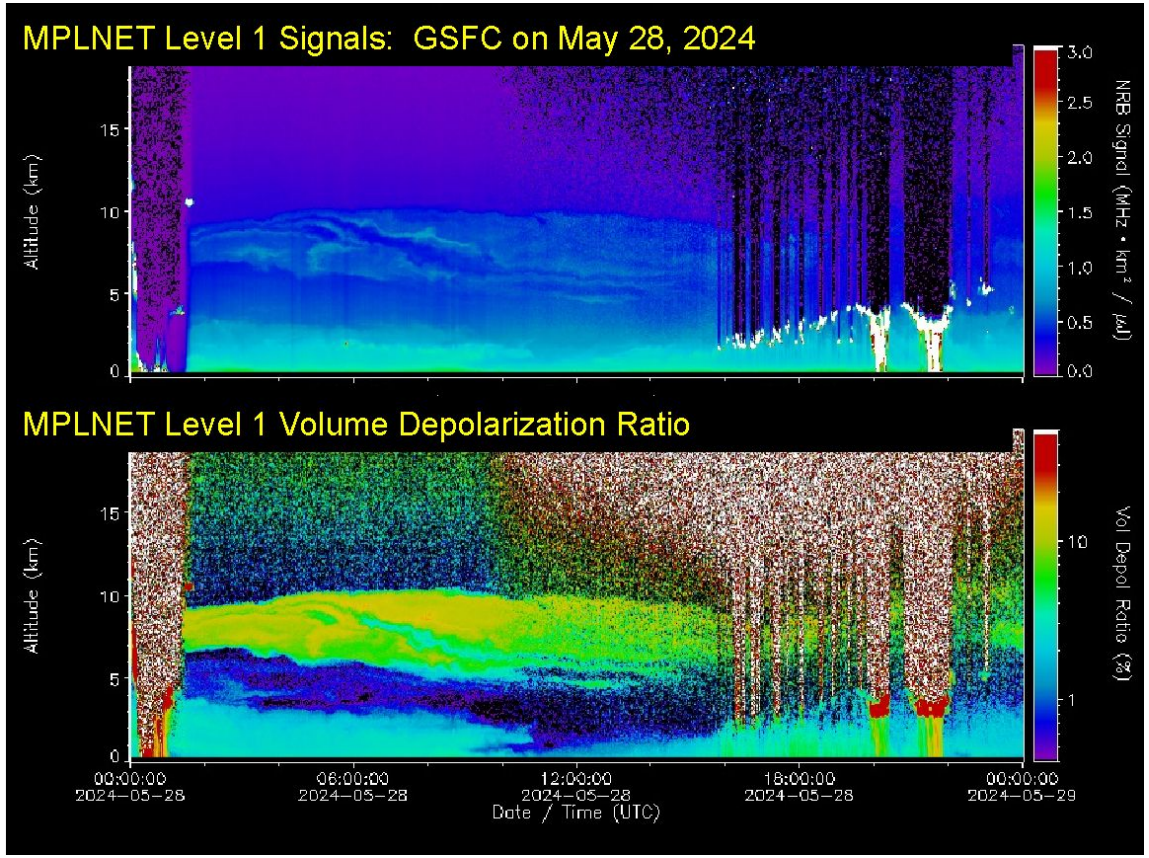
The final aerosol product contains both constrained and interpolated data, the interpolated will be lower quality.

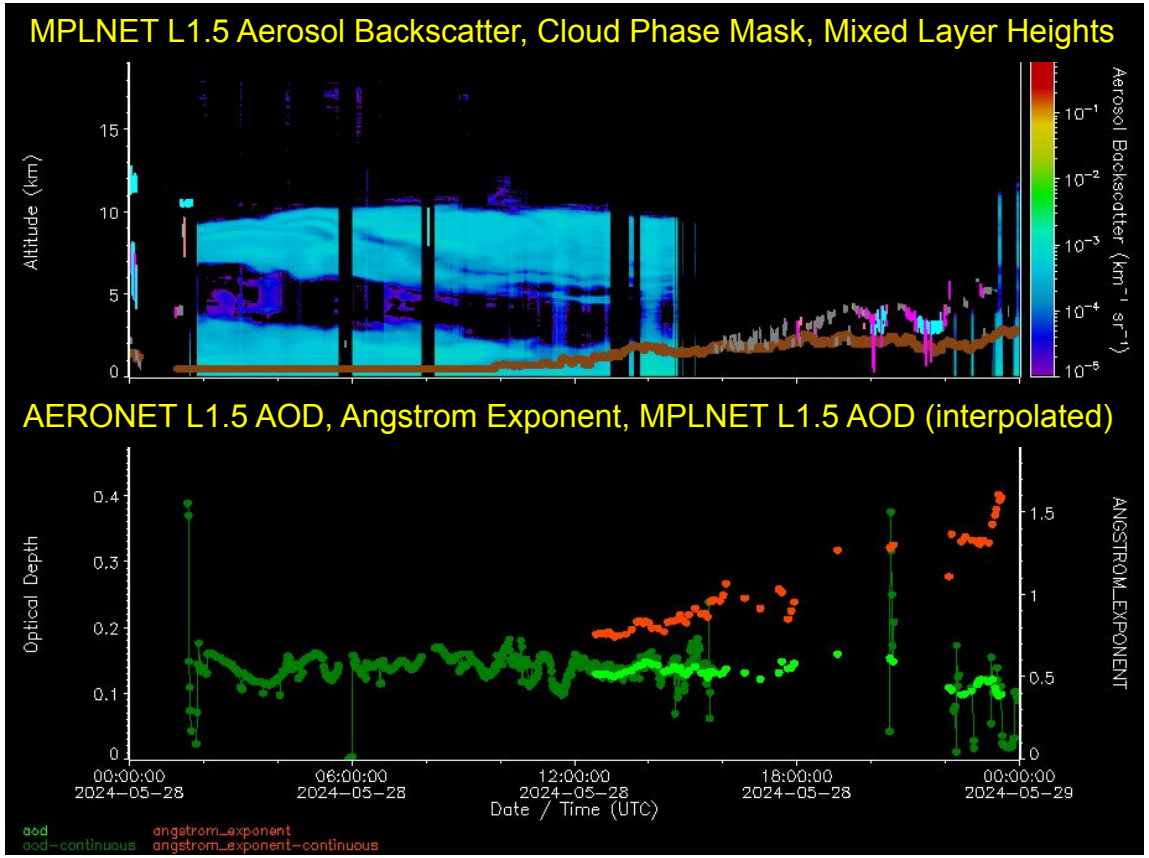
There are a number of other QA flags in the product, including indication of which AOD was used: day, night, or interpolated.

MPLNET: How we have supported AERONET

- Signal and Depol Ratio profiles provide atmospheric structure information
- Coincident aerosol height and backscatter & extinction profiles expand upon column observations

MPLNET V3 Lidar Signals and Aerosol Product:

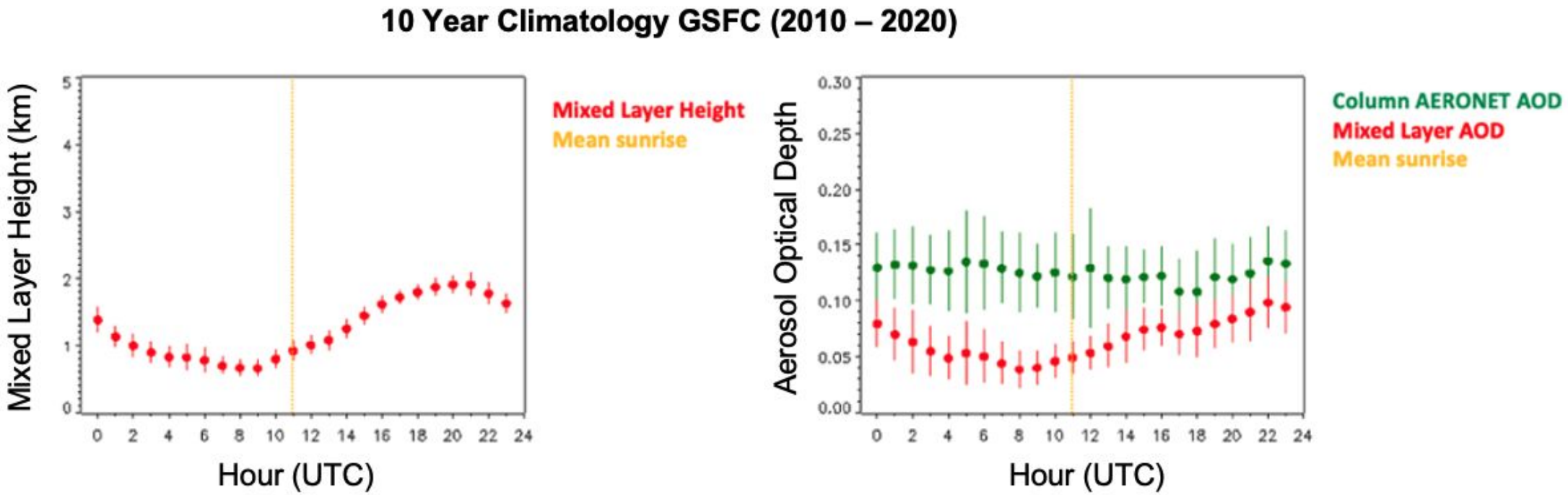




MPLNET: How we have supported AERONET

- Separation of column AOD to mixed layer and free tropospheric AOD components

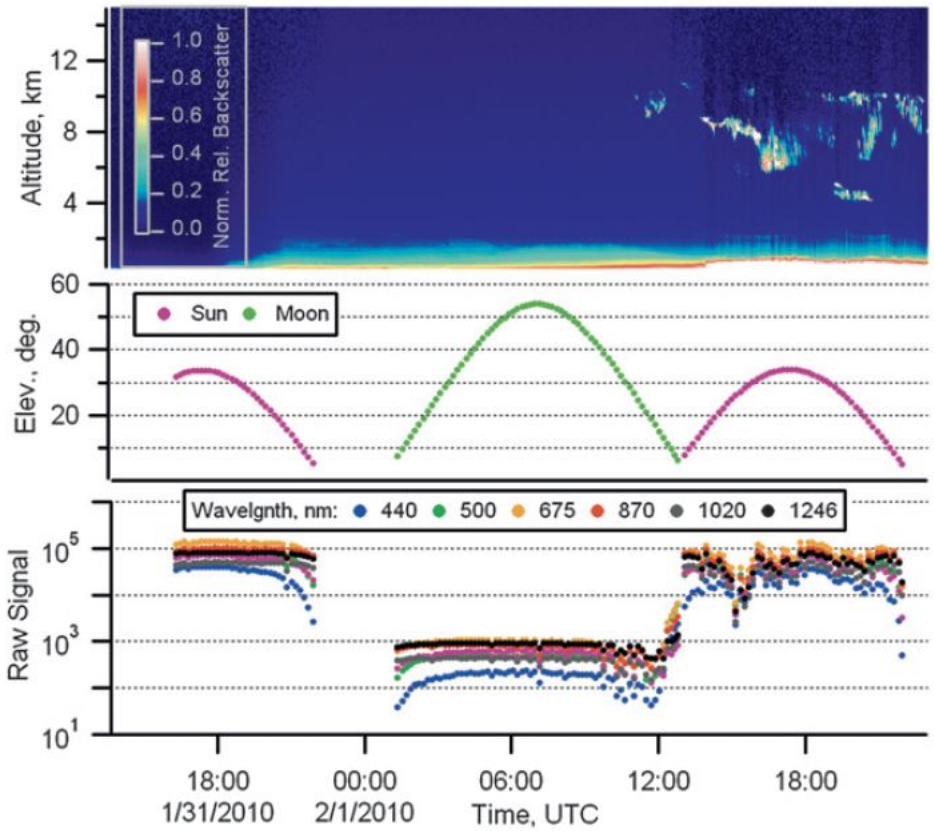
MPLNET V3 PBL Product:



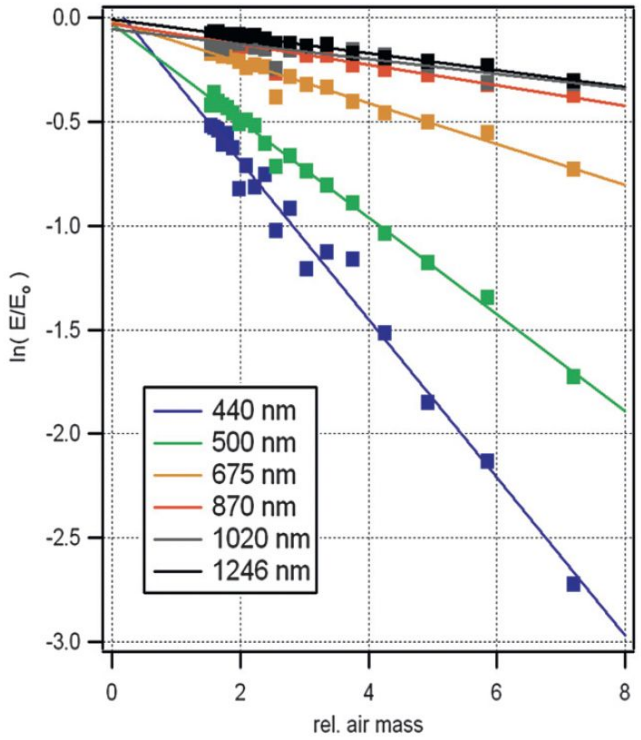
MPLNET: How we have supported AERONET

- Cimel Lunar AOD development began in MPLNET. Goal: duplicate our lidar retrievals during nighttime
- Proof of concept paper 2011, transitioned to AERONET for implementation
  - Berkoff, et al., Nocturnal Aerosol Optical Depth Measurements with a Small-Aperture Automated Photometer Using the Moon as a Light Source, JTECH, DOI: 10.1175/JTECH-D-10-05036.1, 2011

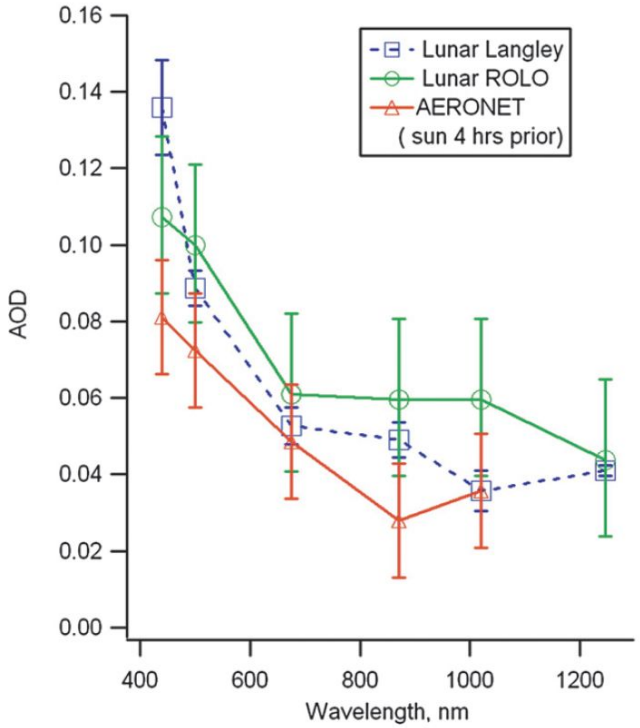
GSFC Feb 1, 2010
MPLNET NRB & Raw Cimel Signals



Langley Calibrations



Lunar vs Daytime AOD

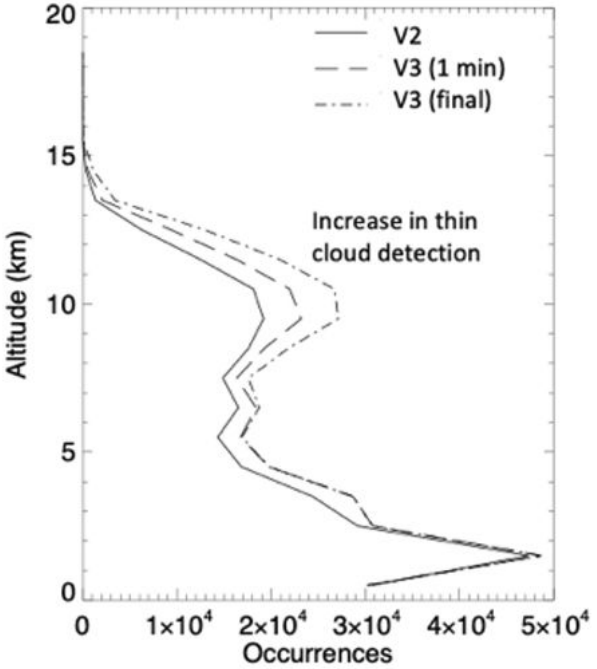


MPLNET: How we have supported AERONET

- Cloud Location and Screening
  - MPLNET V3 cloud data used in development of AERONET V3 cirrus screening
  - Support studies of aerosol-cloud interactions

MPLNET V3 Cloud Product:

Lewis, J.R. et al. Overview of MPLNET Version 3 Cloud Detection, 2016.
Lewis, J.R. et al. Determining Cloud Thermodynamic Phase from the Polarized Micro Pulse Lidar, 2020.



Cloud detection comparison 2012 GSFC: Older V2 results (detection only at 1 minute temporal res). V3 algorithm results at 1 minute, and the final multi-temporal results.

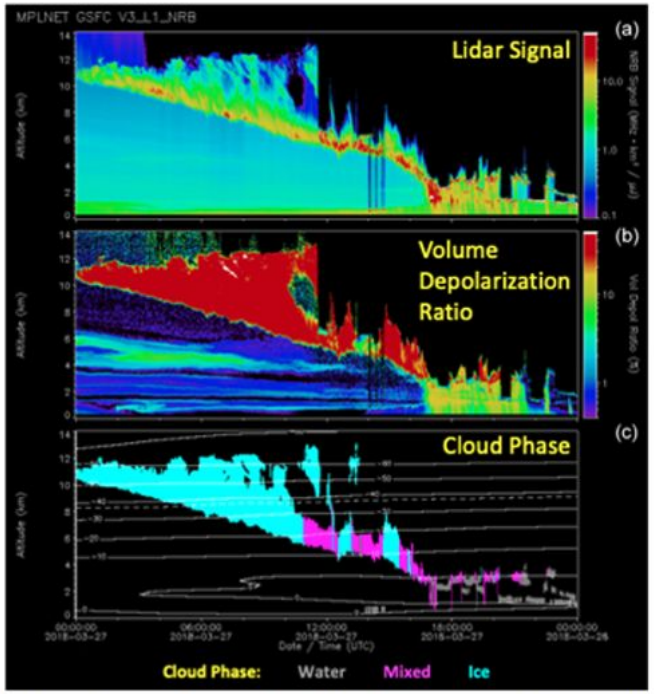


Figure 6. Frontal cloud system at GSFC on 27 March 2018: NRB (a), volume depolarization ratio (b) and phase mask (c). Altitude bins where the signal uncertainty is twice the signal strength have been suppressed for easier viewing. Note the use of a log scale for the NRB. The phase mask indicates liquid water clouds (grey), mixed-phase clouds (magenta), ice clouds (cyan), and unknown phase (pink). The GEOS-5 temperature is shown by the contour lines (in 10 °C intervals). The −37 °C isotherm is indicated by the dashed contour line.

AERONET V3 Cirrus Screening:

Giles, D.M., et al, Advancements in the Aerosol Robotic Network (AERONET) Version 3 Database – Automated Near Real-Time Quality Control Algorithm with Improved Cloud Screening for Sun Photometer Aerosol Optical Depth (AOD) Measurements, 2019.

Table 3. AERONET and MPLNET sites and date ranges used for assessing cirrus and non-cirrus cloud presence.

Site	Latitude	Longitude	Elevation (m)	Date range
GSFC	38.9925	−76.8398	87	May 2001–Jan 2013
COVE	36.9000	−75.7100	37	May 2004–Jan 2008
Kanpur	26.5128	80.2316	123	May 2009–Jan 2013
SEDE_BOKER	30.8550	34.7822	480	Nov 2007–Apr 2013
Santa_Cruz_Tenerife	28.4725	−16.2473	52	Nov 2005–Jan 2013
Singapore	1.2977	103.7804	30	Aug 2009–Jan 2013
Ragged_Point	13.1650	−59.4320	40	Jun 2008–Jan 2013
Trinidad_Head	41.0539	−124.1510	105	May 2005–Feb 2013

Current Focus: Smoke Research and Increasing Importance

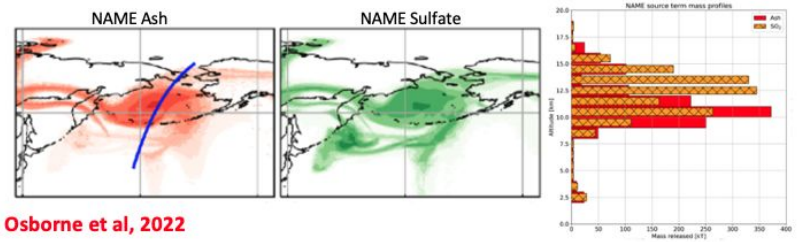
MPLNET Contributions to Wildfire Smoke Research. Also recognition of a growing problem in the Northern Hemisphere….

Northern Hemisphere is becoming an increasingly complex aerosol environment from surface to stratosphere for most of the year!

Modeled Emissions Alberta Fire June 2019

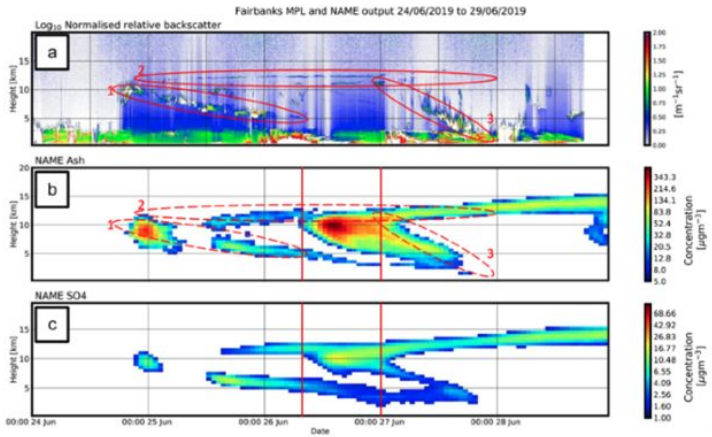
from Osborne et al, 2022

Modeled Emissions Raikoke Volcano June 2019



from Osborne et al, 2022

MPLNET Observations Fairbanks Alaska, Modeled Ash and SO4 Plumes



---------- **South East Asian Smoke** ----------

Salinas, S.V., et al, 2012. Physical and optical characteristics of the October 2010 haze event over Singapore: A photometric and lidar analysis. Atmos. Res., doi:10.1016/j.atmosres.2012.05.021.

Chew, B.N., et al, 2013. Aerosol particle vertical distributions and optical properties over Singapore, Atmos. Environ., 79, 599-613, doi:10.1016/j.atmosenv.2013.06.026.

Wang, S.H., et al, 2015. Vertical Distribution and Columnar Optical Properties of Springtime Biomass-Burning Aerosols Over Northern Indochina During 2014 7-SEAS Campaign, Aerosol Air Qual. Res., 15, 2037-2050, doi: 10.4209/aaqr.2015.05.0310.

Campbell, J.R., et al, 2016. Applying Advanced Ground-Based Remote Sensing in the Southeast Asian Maritime Continent to Characterize Regional Proficiencies in Smoke Transport Modeling. J. App. Meteorol. Clim., 55, 3-22, DOI:10.1175/JAMC-D-15-0083.1.

Lee, J, et al, 2016. Evaluating the height of biomass burning smoke aerosols retrieved from synergistic use of multiple satellite sensors over Southeast Asia. Aerosol Air Qual. Res., 16, 2831–2842, doi:10.4209/aaqr.2015.08.0506.

---------- **North American and European Smoke** ----------

Colarco, P.R., et al, 2004. Transport of smoke from Canadian forest fires to the surface near Washington, D.C.: Injection height, entrainment, and optical properties, J. Geophys. Res., 109, D06203, doi:10.1029/2003JD004248.

Lund Myhre, C., et al, 2007. Regional aerosol optical properties and radiative impact of the extreme smoke event in the European Arctic in spring 2006, Atmos. Chem. Phys., 7, 5899-5915.

Miller, D.J., et al, 2011. Assessing boreal forest fire smoke aerosol impacts on U.S. air quality: a case study using multiple datasets, *J. Geophys. Res.*, 116, D22209, doi:10.1029/2011JD016170.

Loría-Salazar, S.M., et al, 2021. Evaluation of Novel NASA MODIS and VIIRS Aerosol Products and Assessment of Smoke Height Boundary Layer Ratio During Extreme Smoke Events in the Western U.S., J. Geophys. Res. Atmos., 126, https://doi.org/10.1029/2020JD034180.

Eck T. F., et al, A. R. Menendez, 2023. The extreme forest fires in California/Oregon in 2020: Aerosol optical and physical properties and comparisons of aged versus fresh smoke, Atmos. Environ., 305, https://doi.org/10.1016/j.atmosenv.2023.119798.

---------- **Volcanic Plumes** ----------

Sicard, M., et al, 2022. Volcanic Eruption of Cumbre Vieja, La Palma, Spain: A First Insight to the Particulate Matter Injected in the Troposphere. Remote Sensing, 14, https://doi.org/10.3390/rs14102470

Sellitto, P., et al, 2023. Volcanic emissions, plume dispersion, and downwind radiative impacts following Mount Etna series of eruptions of February 21–26, 2021. J. Geophys. Res. Atmos., 128, https://doi.org/10.1029/2021JD035974

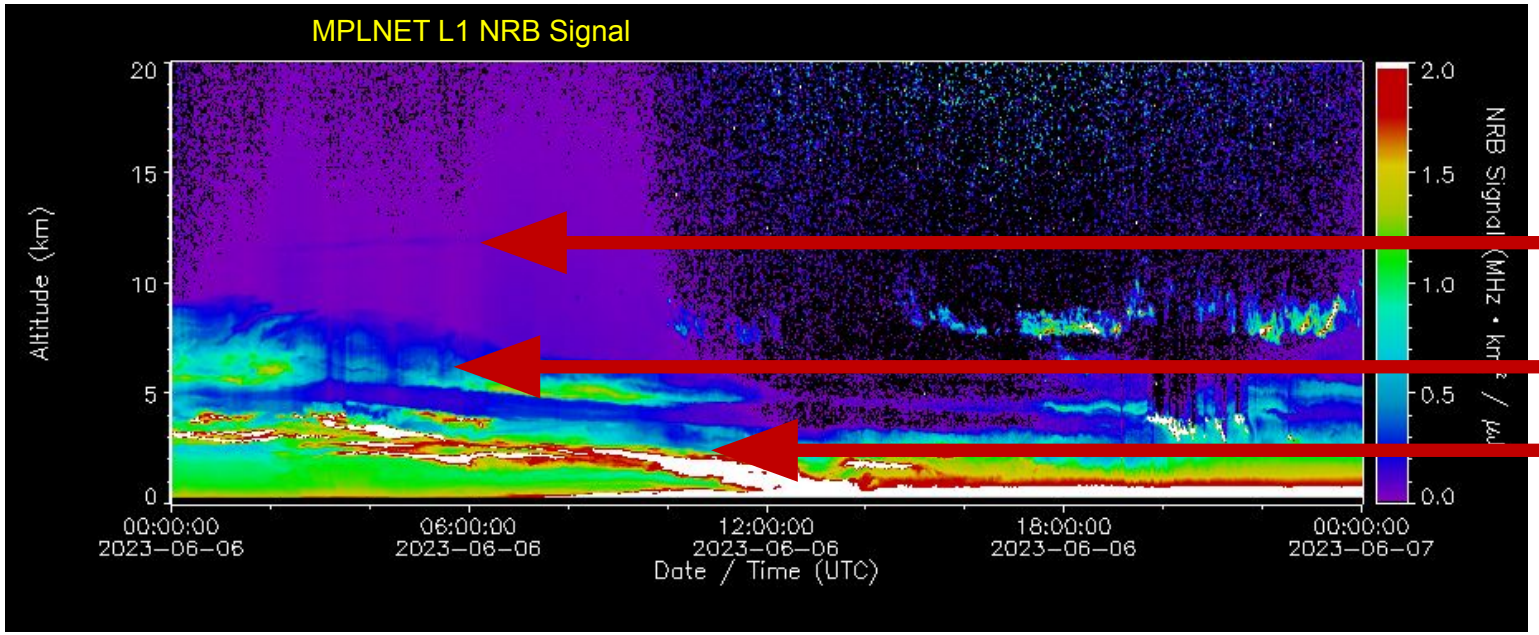
---------- **Northern Hemisphere Smoke AND Volcanic Plumes** ----------

Osborne, M., et al, 2022. The 2019 Raikoke volcanic eruption part 2: Particulate phase dispersion and concurrent wildfire smoke emissions. Atmos. Chem. Phys., 22, 2975–2997, https://doi.org/10.5194/acp-22-2975-2022.

Shang, X., et al, 2024. Monitoring biomass burning aerosol transport using CALIOP observations and reanalysis models: a Canadian wildfire event in 2019. *Atmos. Chem. Physics.*, Accepted.

Current Focus: Smoke Research and Increasing Importance

The "wall of smoke" example from MPLNET measurements at GSFC on June 6, 2023



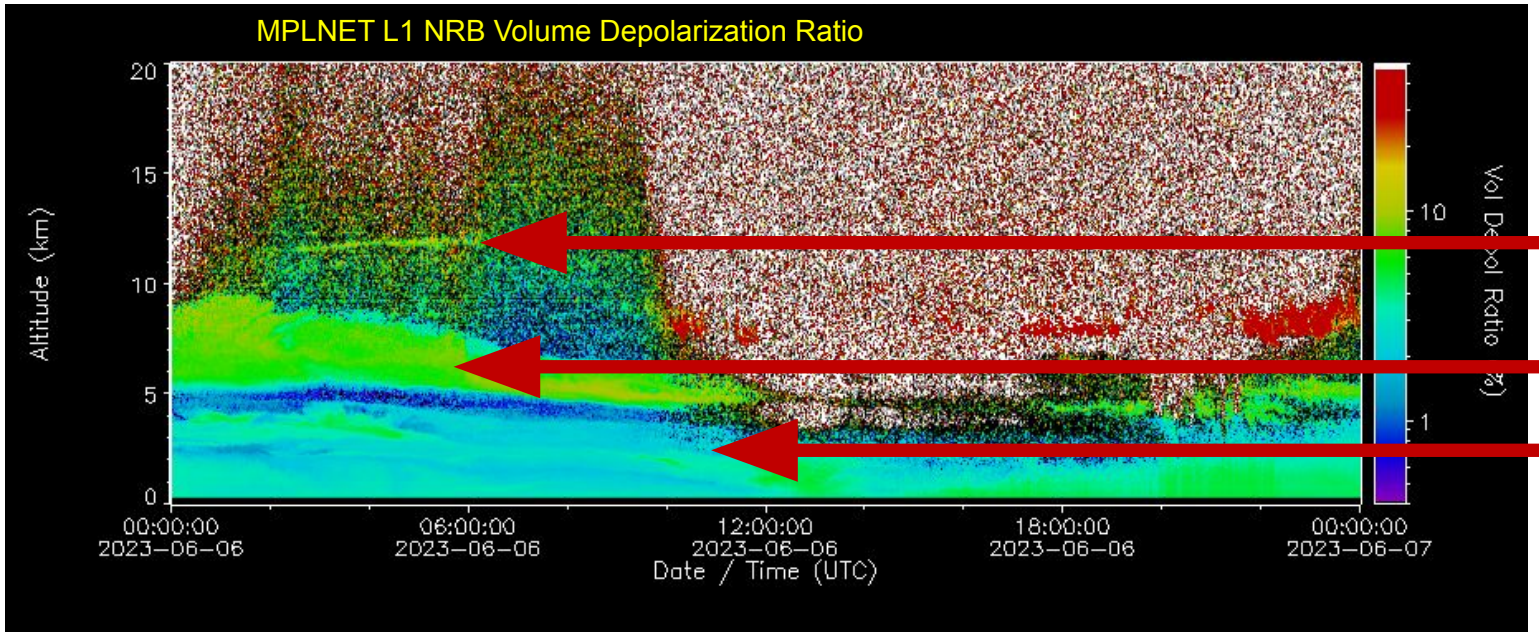
Smoke from older fires after circumnavigation

Smoke from Western Canadian Fires

Smoke from Eastern Canadian Fires

Current Focus: Smoke Research and Increasing Importance

The "wall of smoke" example from MPLNET measurements at GSFC on June 6, 2023



Smoke from older fires after circumnavigation

Smoke from Western Canadian Fires

Smoke from Eastern Canadian Fires

- Less depolarizing
- More spherical particles

These conditions are becoming prevalent for much of the year, especially in the Northern Hemisphere

There is an urgent need for lidar profiling to cover wide spatial and temporal scales

- Combination of satellite and network observations

Up Next: ESA EarthCARE Validation and Joint Research

The ESA EarthCARE mission includes ATLID, the next satellite lidar (in commissioning phase now). Data will be available soon.
ATLID is a polarized High Spectral Resolution Lidar (HSRL) operating at 355 nm.
MPLNET is a member of the ESA EarthCARE validation team (PI Welton, Co-PI Lewis)

Task 1: Validate aerosol, cloud, and planetary boundary layer heights using L3 MPLNET products

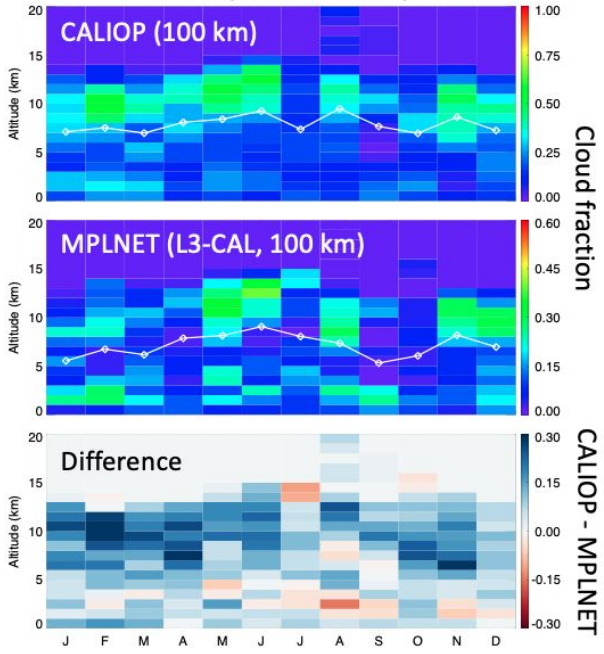
Task 2: Compare drizzle occurrence and properties

Task 3: Evaluate EarthCARE-based cirrus datasets for TOA CRE (top-of-atmosphere cirrus cloud radiative effect)

Examples of EarthCARE validation using CALIPSO data and simulated EarthCARE data

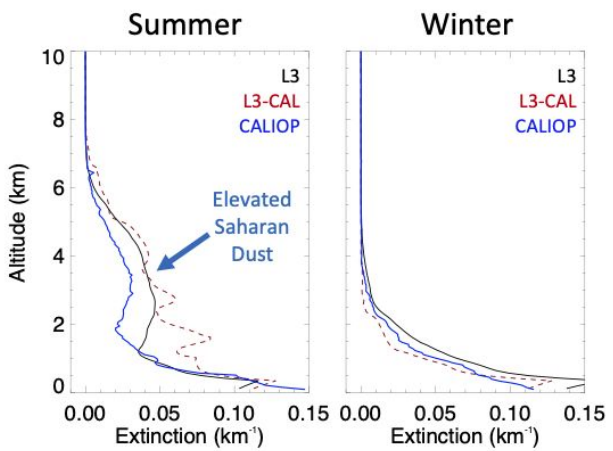
Cloud Occurrence

GSFC (2016 – 2021)



Aerosol Profiles

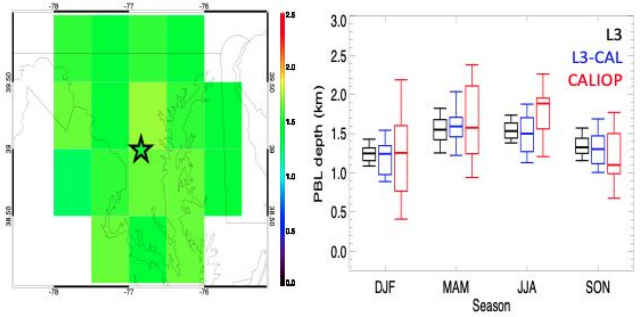
Santa Cruz Tenerife (2018 – 2021)



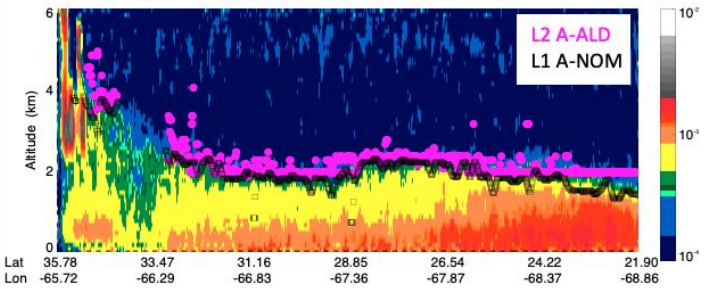
*Due to the difference in MPLNET/ATLID wavelengths, we will not attempt to validate extinction profiles. However, we will evaluate aerosol layer heights

Planetary Boundary Layer Height

GSFC (2016 – 2021)



Simulated Halifax Aerosol Scene



J. Lewis PI: validation and science proposal through the NASA Earth Science US Participating Investigator Program

MPLNET: Summary

Version 3 continues

- Reprocessing archive and release of Level 2 data, delayed due to server constraints and COVID
- Finalizing development of Level 3 products (monthly, diurnal averages)
- Moving to a hybrid configuration of on-premises server and Amazon Web Services
- Backups of project
- More flexibility and computing power (Level 2)
- Version 4 development, eventual home in AWS

Completion of network expansion

- MPLCAN subnet (newest site Stony Plain, near Edmonton)
- Installation of sites in Western North America for smoke observations closer to fires

Planning for next 5 year cycle

- Proposal due end of October

Continuing and strengthening our collaborations with other lidar networks

- See poster on the WMO GAW Aerosol Lidar Observation Network (GALION)
- A network of lidar networks approach to global coverage on the scale of AERONET

Conclusion

My sincere thanks to AERONET:
Past, current, and future members …

… and Brent in particular

Somewhere on week 3 in Asia

Hopefully you are getting some much needed rest now