MPLNET Observations in Support of EarthCARE Cal/Val

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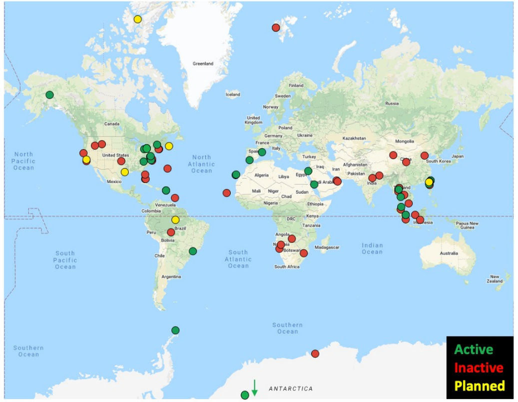
Ellsworth J. Welton (NASA), Jasper R. Lewis (UMBC/NASA), James R. Campbell (NRL), Simone Lolli (CNR)

MPLNET: Overview and News Since Last Workshop

MPLNET Sites: 2000 - current



MPLNET - Global Backscatter Lidar Network: 2000 - current

- 75 sites total (25 active, 50 inactive). 27 countries, 45 partners.
- 7 more planned sites
- Continuous (day/night) operations
- 97% of network co-located with AERONET
- Created using AERONET model: federated network with centralized and standardized calibration, processing, distribution. Same open data policy (with co-authorship offer).

Instrumentation:

- Micro Pulse Lidar (NASA developed, commercial since 1995)
- Eye safe, green backscatter lidar. Polarized in early 2000s
- Entire network has polarized MPL since ~2016

ESA EarthCARE MPLNET Validation Team: Ellsworth J. Welton (PI), J.R. Lewis (Co-I), J.R. Campbell (Co-I), S. Lolli (Co-I)

- Baseline MPLNET funding will provide support of site operations (joint with our international partners), and calibration, QC/QA, data processing (raw to L1,L1.5,L2,L3), and data archival and distribution
- PI Welton is the POC for deployment of new MPLNET sites specific to EarthCARE validation

NASA Participating Investigator Program Validation Team: 5 YR (2021-2026) Proposal to support our EarthCARE validation was funded

- Jasper R. Lewis (PI). Co-Is: E.J. Welton (Co-I), J.R. Campbell (Co-I), S. Lolli (Co-I). Collaborators: Rob Koopman (ESA), Michaël Sicard (UPC)
- This effort will fund MPLNET-EarthCARE data analysis and development of EarthCARE specific L3 products to be uploaded to EVDC
- Jasper will be the primary POC for MPLNET – EarthCARE validation products and studies

MPLNET: Version 3 Product Suite

Online Product Information: https://mplnet.gsfc.nasa.gov/product-info/

Version 3 Products

- EarthCARE cal/val will focus only on variables not dependent upon wavelength (MPL at 532 nm)
- All products contain variable uncertainties and QA flags

V3 Product	Descriptions
NRB	Lidar signals; volume depolarization ratios; diagnostics
CLD	Cloud heights; thin cloud extinction and optical depth; 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.

PRC: Light Precipitation product in beta test

Version 3 Product Levels

- All L1 and L1.5 products available in NRT (< 1 hour) via automated data transfer and processing
- NRT QA screen applied at L1.5, final QA at L2
- L3 products in development (created from L2 data)

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	upon request †	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
† L2_AER products subject to availability of L2 AERONET data
‡ Additional L2 calibrations may include corrections for instrument temperature and manual inspection of data

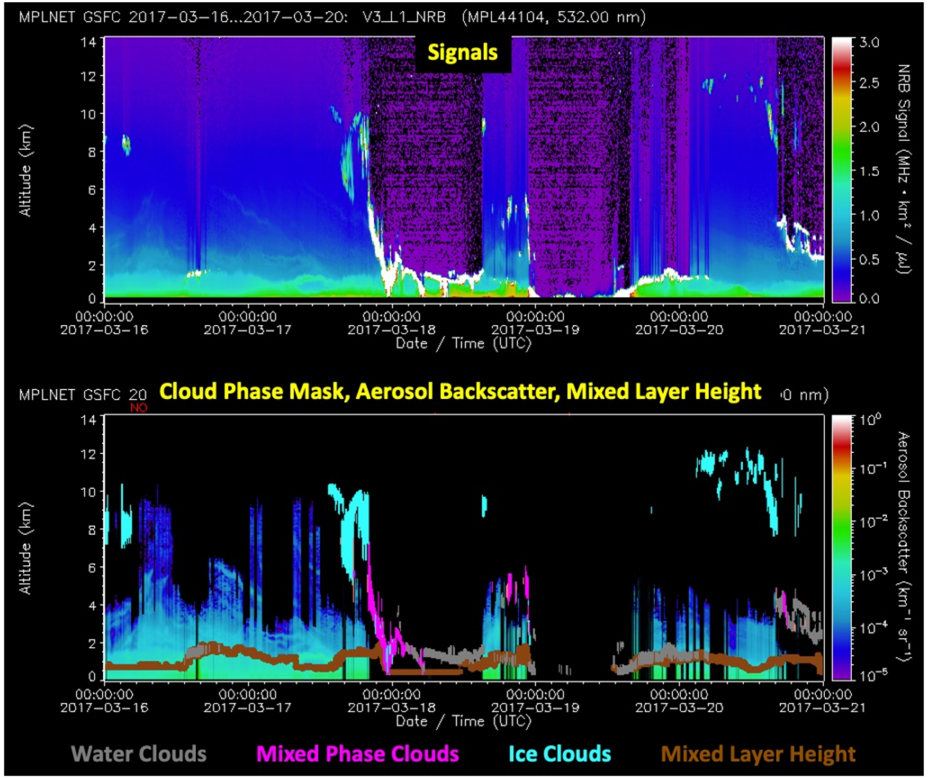
Version 3 Variable Confidence Flags

- New for Version 3, in all products
- Based on maturity of variable algorithm and QC/QA flags

QA Confidence Level	Value	Descriptions
n/a	0	Only set if variable has no QA inspection applied.
High	1	Long history with variable and QA procedures results in high confidence
Moderate	2	Lower confidence in an ancillary data input results in lower overall QA confidence
Low	4	Reserved for variables that are new and require more study to elevate confidence
Fail	8	Data fail QA screen, variable data replaced with NaN

MPLNET: Version 3 Product Suite Examples

MPLNET GSFC: 2017-03-16 to 2017-03-20



MPLNET: NRB Product Signal Calibrations and QA Flags

Original MPL Calibrations and Signal Processing:

- Detector Deadtime
- Dark Count
- Afterpulse
- Range offset corrections
- Overlap (old method: Version 1)
- Raw to Relative Attenuated Backscatter (C•ATB)

- Updated Overlap calibrations using additional wide field receiver (Version 2 – 3)
    - Done at GSFC, transferred to MPLs
    - Coming soon, WFR deployed to all MPLs in network

- Campbell, J.R., et al, 2002. Full-time, Eye-Safe Cloud and Aerosol Lidar Observation at Atmospheric Radiation Measurement Program Sites: Instrument and Data Processing, *J. Atmos. Oceanic Technol*., 19, 431-442.
- Welton, E.J., and J.R. Campbell, 2002. Micro-pulse Lidar Signals: Uncertainty Analysis, *J. Atmos. Oceanic Technol.*, 19, 2089-2094.

- T. A. Berkoff, et al, 2003. Investigation of overlap correction techniques for the Micro-Pulse Lidar NETwork (MPLNET). IGARSS 2003. doi: 10.1109/IGARSS.2003.1295527.

Polarized MPL Calibrations and Signal Processing:

- Original polarized MPL (not used in MPLNET)
    - Basic operation unchanged in new polarized MPL

- New Polarized MPL (Ferroelectric Liquid Crystal, FLC)
- Deadtime to Overlap calibration methodology unchanged
- Polarized Model of new polarized MPL developed
- FLC Polarimeter study. Mueller matrix retrieved from 20–30 C
- Calibration approach developed using FLC parameters, polarizing split cube, etc.. and polarized MPL model
- Corrects for both diattenuation and retardance variations leading to cross talk. Gain ratio negligible as MPL is a transceiver. Cross talk bias reduced to < 1%

- Flynn C.J., et al, 2007. Novel polarization-sensitive micropulse lidar measurement technique. Optics Express, 15, 2785-2790, https://doi.org/10.1364/OE.15.002785.

- Welton, E.J., et al, 2018. Status of the NASA Micro Pulse Lidar Network (MPLNET): Overview of the network and future plans, new Version 3 data products, and the polarized MPL. ILRC 2018. EPJ Web of Conferences, 176, https://doi.org/10.1051/epjconf/201817609003.

- NOTE: Full paper on the calibration, processing, and long-term characterization of the polarized MPL is in preparation (delayed from last year due to COVID).

MPLNET: NRB Product Signal Calibrations and QA Flags

flag_data: flag indicating if elastic signal data are missing

Values	Meanings
0B	ignore
1B	data_exists
2B	data_missing

flag_calibration_l0: flag indicating if elastic signal data calibrations were not applied

Values	Meanings
0B	ignore
1B	all_calibrations_applied
2B	deadtime_calibration_missing
4B	darkcount_calibration_missing
8B	afterpulse_calibration_missing
16B	overlap_calibration_missing
32B	polarization_calibration_missing

flag_temperature_correction: flag indicating if elastic signal data temperature corrections were not applied

Values	Meanings
0B	ignore
1B	all_temperature_corrections_applied
2B	overlap_temperature_correction_missing
4B	polarization_temperature_correction_missing
8B	filter_temperature_correction_missing
16B	detector_temperature_correction_missing
32B	window_temperature_correction_missing

flag_energy: flag indicating possible laser energy problems for elastic signal data quality assurance

Values	Meanings
0B	ignore
1B	no_problems
2B	15%_<_energy_deviation_from_set_point_<=_20%
4B	energy_deviation_from_set_point_>_20%
8B	no_set_point
16B	measurement_fault

flag_temp_box: flag indicating possible box telescope temperature problems for elastic signal data quality assurance

Values	Meanings
0B	ignore
1B	no_problems
2B	2C_<_temperature_deviation_from_set_point_<=_5C
4B	temperature_deviation_from_set_point_>_5C
8B	no_set_point
16B	measurement_fault

flag_temp_detector: flag indicating possible detector temperature problems for elastic signal data quality assurance

Values	Meanings
0B	ignore
1B	no_problems
2B	2C_<_temperature_deviation_from_set_point_<=_5C
4B	temperature_deviation_from_set_point_>_5C
8B	no_set_point
16B	measurement_fault

flag_temp_laser: flag indicating possible laser temperature problems for elastic signal data quality assurance

Values	Meanings
0B	ignore
1B	no_problems
2B	placeholder
4B	placeholder
8B	no_set_point
16B	measurement_fault

flag_temp_flc: flag indicating possible FLC temperature problems for elastic signal data quality assurance

Values	Meanings
0B	ignore
1B	no_problems
2B	placeholder
4B	placeholder
8B	no_set_point
16B	measurement_fault

- All of the detailed flag data are summarized in final QA flag below
- This flag is carried forward to all retrieved products to describe signal quality.

flag_qa: overall QA Flag for NRB product

Values	Meanings
0L	ignore
1L	no_problems
2L	flag_calibration_l0
4L	flag_energy
8L	flag_temp_box
16L	flag_temp_detector
32L	flag_temp_laser
64L	flag_temp_flc
128L	flag_temperature_correction

MPLNET Retrieved Products: References

Cloud:

- Lewis, J.R., J.R. Campbell, E.J. Welton, S.A. Stewart, and P.C. Haftings, 2016. Overview of MPLNET Version 3 Cloud Detection. J. Atmos. Oceanic Tech., 33, 2113 – 2134, doi: 10.1175/JTECH-D-15-0190.1.
- Lewis, J.R., J.R. Campbell, S. Lolli, S.A. Stewart, I. Tan, and E.J. Welton, 2020. Determining Cloud Thermodynamic Phase from the Polarized Micro Pulse Lidar. Atmos. Meas. Tech., 13, 6901–6913, https://doi.org/10.5194/amt-13-6901-2020

Aerosol:

- Welton, E.J. K.J. Voss, H.R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J.M. Livingston, P.B. Russell, P.A. Durkee, P. Formenti, M.O. Andreae, 2000. Ground-based Lidar Measurements of Aerosols During ACE-2: Instrument Description, Results, and Comparisons with other Ground-based and Airborne Measurements, Tellus B, 52, 635-650.
- Welton, E.J., K.J. Voss, P.K. Quinn, P.J. Flatau, K. Markowicz, J.R. Campbell, J.D. Spinhirne, H.R. Gordon, and J.E. Johnson, 2002. Measurements of aerosol vertical profiles and optical properties during INDOEX 1999 using micro-pulse lidars, J. Geophys. Res., 107, 8019, doi:10.1029/2000JD000038.

PBL:

- Lewis, J.R., E.J. Welton, A.M. Molod, and E. Joseph, 2013. Improved boundary layer depth retrievals from MPLNET, J. Geophys. Res., 118, 9870-9879, doi:10.1002/jgrd.50570.

Precipitation:

- Lolli, S., G. Vivone, J.R. Lewis, M. Sicard, E. J. Welton, J.R. Campbell, A. Comeron, L. P. D'Adderio, A. Tokay, A. Guinta, and G. Pappalardo, 2020. Overview of the new Version 3 MicroPuLse NETwork (MPLNET) automatic precipitation detection algorithm. Remote Sens. 12(1), 71; https://doi.org/10.3390/rs12010071

MPLNET: Validation of our products

Series of papers validating MPLNET extinction & AOD profile retrievals against NASA Ames Airborne Tracking Sunphotometer

- Validation of our aerosol retrieval technique using AERONET AOD as constraint (Welton et al 2000)
- Indirectly validates our lidar calibrations and QA process as the aerosol retrievals are very sensitive to all cals (especially the overlap)

Schmid, B., et al, 2000. Clear sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne, and ground-based measurements, *Tellus B*, 52, 567-592

Schmid, B., et al, 2003. Coordinated airborne, spaceborne, and ground-based measurements of massive, thick, aerosol layers during the dry season in Southern Africa, *J. Geophys. Res.*, 108, 8496, doi:10.1029/2002JD002297

Livingston, et al, 2003. Airborne Sun photometer measurements of aerosol optical depth and columnar water vapor during the Puerto Rico Dust Experiment and comparison with land, aircraft, and satellite measurements, *J. Geophys. Res.*, 108, 8588, doi:10.1029/2002JD002520

Schmid, B., et al, 2006. How well do state-of-the-art techniques measuring the vertical profile of tropospheric aerosol extinction compare?, *J. Geophys. Res.*, 111, D05S07, doi:10.1029/2005JD005837

- Schmid et al 2006: State of the art aerosol extinction measurement intercomparisons
    - MPLNET met the average bias, and exceeded some other techniques

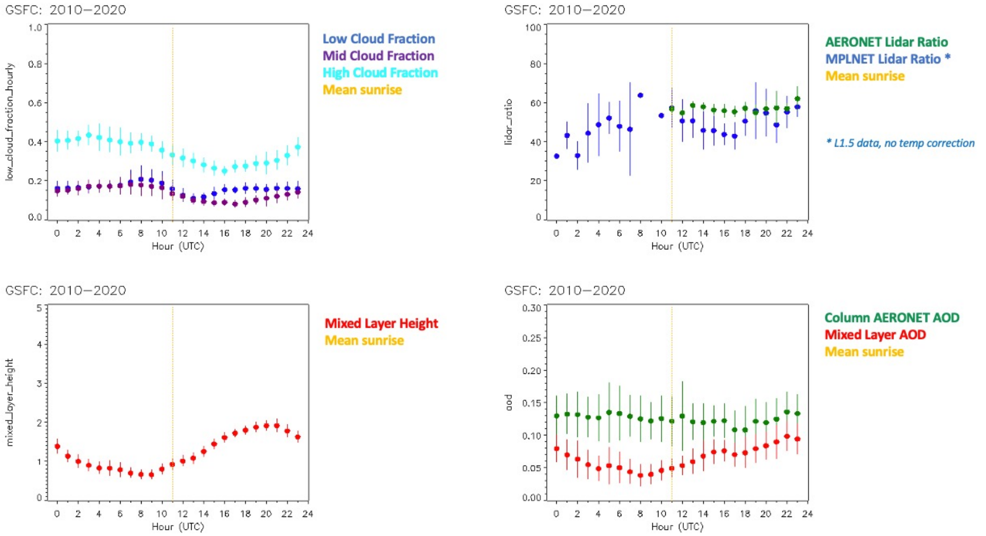
- We now have some joint sites with both EARLINET and LALINET, which offer opportunities for inter-network comparisons
    - No joint sites with ADNET yet, but this could be done (many MPLNET sites in Asia)
- Our partners at UMBC operate numerous ceilometers and lidars, and could provide a US based inter-calibration site that already has MPLNET and is near our HQ at NASA.

MPLNET: Level 3 Products in Development

Exploit Diurnal Capability of Long-term MPLNET Data

- 12 sites with 10+ years of data
- 10 sites with 5 – 9 years of data
- 2 sites with 20+ years of data (GSFC and South Pole)
- We are developing L3 products for the first time
    - Objective: go from instantaneous L2 profiles to monthly, seasonal, annual, and decadal climatologies
    - Standard L3 product files will be monthly diurnal averages for full product suite (NRB, CLD, AER, PBL)
    - Custom L3 products will be developed for EarthCARE
    - This provides a statistical approach for EarthCARE validation that avoids problems matching ground-based observations with direct satellite overflights (especially important for narrow swath instruments)

MPLNET L3 Decadal Examples: 2010-2020 GSFC



MPLNET: EarthCARE Cal/Val

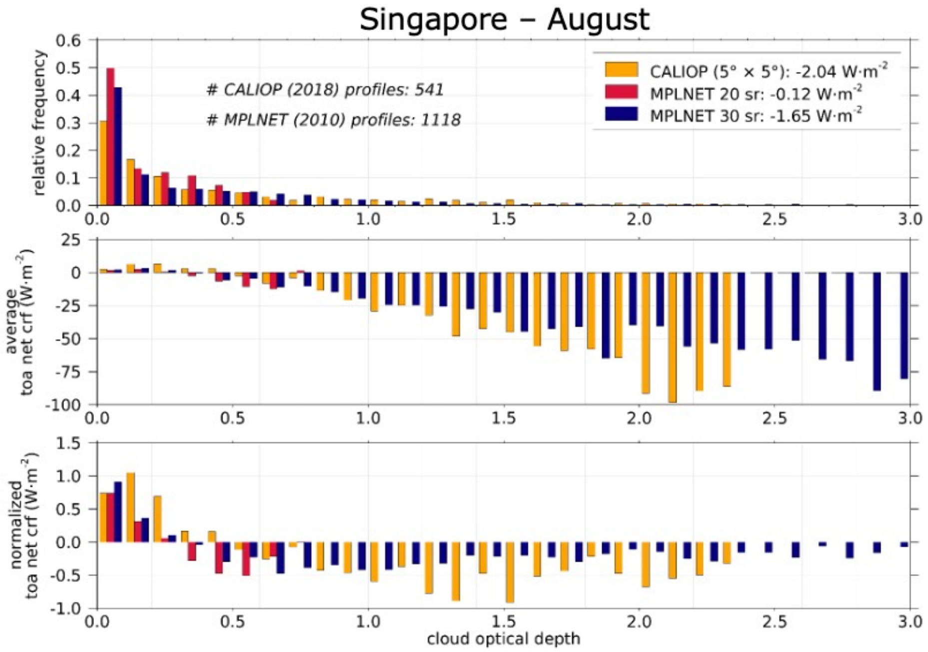
- **Task 1: Validate aerosol, cloud, and planetary boundary layer heights**
  - L3-EC products will be provided to the EVDC (new templates needed?)
  - Same statistical analysis used for standard MPLNET L3 products, but constrained to within 200-km /2-hr of EarthCARE overpass
  - Considerations
    - Known differences in wavelength (532-nm vs. 355-nm) and meteorological parameters (GEOS-5 vs. ECMWF)
    - Narrow MPL FOV (~100 μrad) minimizes multiple scattering effects

Product	Description
L3-EC_NRB	Contains lidar signal and diagnostic information. Not specifically used for validation of any EarthCARE product because of wavelength differences (532-nm vs. 355-nm). However, the MPLNET signal profiles will provide context with interpreting results.
L3-EC_CLD	Contains information about cloud layer heights and cloud phase. Will be used to validate EarthCARE feature mask, target classification, and cloud top height products (A-FM, A-TC, AC-TC, A-CTH, AM-CTH).
L3-EC_AER	Contains information about aerosol layer heights. Will be used to validate EarthCARE feature mask, target classification, and aerosol layer descriptor (A-FM, A-TC, AC-TC, A-ALD).
L3-EC_PBL	There is no specific PBL product in the EarthCARE product suite. However, the PBL is intrinsically contained in the A-ALD product as the top height of the aerosol layer in contact with the ground [89]. If necessary, we may employ other methods [90, 91] used with CALIOP to determine an independent PBL height for EarthCARE.

- **Task 2: Compare drizzle occurrence and properties**
  - Automated precipitation detection has been incorporated into MPLNET processing (beta testing)
  - Will be used to identify potential case studies for drizzle from CPR products (C-TC, C-CLD)

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

- Fu-Liou-Gu model used to solve cirrus cloud radiative properties of single-layered cirrus clouds
- Results from EarthCARE will be compared to similar TOA CRE from MPLNET and historical CALIPSO dataset
    - See series of papers (2016 – current) on cirrus TOA forcing on MPLNET website



- A comparison of **MPLNET** and **CALIOP**-derived cirrus TOA net CRE
- CALIOP seemingly fails to resolve some of the optically thinnest cirrus
- The cirrus TOA net CRE is stronger (more negative) than that solved from MPLNET data
- How well will EarthCARE resolve thin cirrus?

MPLNET: Conclusion