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Micropulse Lidar (MPL) Instrument Handbook

P Muradyan R Coulter

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ARM

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P Muradyan
R Coulter
Both at Argonne National Laboratory

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Acronyms and Abbreviations

AMF	ARM mobile facility
ANL	Argonne National Laboratory
APD	avalanche photodiode
ARM	Atmospheric Radiation Measurement
ARSCL	Active Remotely Sensed Cloud Locations
ASI	Ascension Island
AWARE	ARM West Antarctic Radiation Experiment
CF	Central Facility
COMBLE	Cold-Air Outbreaks in the Marine Boundary Layer Experiment
CW	continuous wave
DQO	Data Quality Office
ENA	Eastern North Atlantic
FS	fast switching
ICECAPS	Integrated Characterization of Energy, Clouds, Atmospheric State, and Precipitation over Summit
LANL	Los Alamos National Laboratory
MAGIC	Marine ARM GPCI Investigations of Clouds
MARCUS	Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean
MOSAIC	Multidisciplinary Drifting Observatory for the Study of Arctic Climate
MPL	micropulse lidar
MPLNOR	MPL normalized
NASA	National Aeronautics and Space Administration
NRB	Normalized Relative Backscatter
NSA	North Slope of Alaska
PC	personal computer
QC	quality control
RHUBC-II	Radiative Heating in Underexplored Bands II
SGP	Southern Great Plains
STORMVEX	Storm Peak Lab Cloud Property Validation Experiment
SW	shortwave
TCAP	Two-Column Aerosol Project
TWP	Tropical Western Pacific
UK	United Kingdom
VAP	value-added product
WAIS	West Antarctic Ice Sheet
WFR	wide field receiver

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1.0 General Overview

The micropulse lidar (MPL) is a ground-based, autonomous, eye-safe lidar operating at 532 nm. It operates by transmitting a short pulse of laser light through the telescope and detecting a portion of light that has been backscattered by atmospheric particulates. The backscattered energy is collected at the transceiver and measured as a time-resolved signal. From the time delay between each outgoing transmitted pulse and the backscattered signal, the distance to the scatterer is inferred.

This active remote-sensing instrument is generally used for real-time detection of clouds. Post-processing of the lidar return can also help characterize the extent and properties of aerosol or other particle-laden regions.

2.0 Contacts

2.1 Mentor

Paytsar Muradyan
Environmental Science Division
Argonne National Laboratory
Phone: (630) 252-1657
Email: pmuradyan@anl.gov

Richard Coulter
Environmental Science Division
Argonne National Laboratory
Phone: (630) 252-5833
Email: rlcoulter@anl.gov

2.2 Vendor/Instrument Developer

Micro Pulse LiDAR, part of Hexagon
Sold through Leica Geosystems, Inc.
5051 Peachtree Corners Circle, Suite 250
Norcross, Georgia 30092
Phone: (770) 326-9500
www.micropulselidar.com

3.0 Deployment Locations and History

Prior to August 2006, the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's MPLs were located at:

- Southern Great Plains (SGP), Central Facility (C1)

- North Slope of Alaska (NSA), Barrow (C1)
- Tropical Western Pacific (TWP), Manus Island, Papua New Guinea (C1)
- TWP, Nauru Island (C2)
- TWP, Darwin, Australia (C3).

These systems were non-polarized systems. In August 2006, new dual-polarization lidars were put in place that detect the backscatter light in two orthogonal linear polarization channels – “co-polarized” (co-pol/parallel) and “cross-polarized” (cross-pol/orthogonal). This allows comparison of the co-pol and cross-pol signals to distinguish between spherical (e.g., water) and non-spherical (e.g., ice) scattering particles. The dual-polarized MPL systems switched polarization states at 3–10 second intervals. Beginning in 2009, they were upgraded to “fast-switching” (FS) capability between the channels, enabling switching on every pulse (2500 Hz rate).

The location and deployment history since 2006 is given in Table 1.

Table 1. ARM MPL location and deployment history.

Date	MPL	Site	Diode Hours	Comments
11/07/06	102			SWAP 1.67A->1.0W (OLD MPL)
5/03/07	104	Darwin		SWAP 0.85A->2.4uJ (low output)
5/15/07	104	Darwin		MPL removed for repair
5/15/07	101	Darwin		MPL installed
10/10/07	106	SGP		New detector installed
12/19/07	104	SGPTST		MPL installed at SGP Central Facility Guest Instrument trailer
7/14/08	409	5406		MPL first tried at ANL after return from China
9/03/08	409	ANL		MPL shipped to Sigma Space for repair
9/24/08	101	Darwin		SWAP 1.5A->0.7W (low output)
9/30/08	102	Manus	0051	Hour status, no laser output
11/18/08	101	Darwin		SWAP 1.55A->1.0W
11/19/08	104	FSPOL		MPL FSPOL upgrade to SGP CF
12/02/08	104	FSPOL		MPL installed at SGP CF trailer
1/27/09	106	SGP		New detector installed
2/04/09	102	Manus		Swap, but faulty photonics
2/13/09	108	Nauru		MPL removed to go to Darwin
2/26/09	101	Darwin		Removed for repair by Sigma Space
2/26/09	108	Darwin		MPL installed
2/26/09	409	ANL		Received from Sigma Space repaired
2/27/09	104	FSPOL		Shipped to Pagosa for RHUBC-II
3/17/09	105	NSA	52941	Diode swap
3/31/09	409	ANL		Connected at ANL for test, OK
4/01/09	106	SFP	4498	Hour status
4/09/09	108	Darwin	0256	Hour status
4/13/09	105	NSA	22719	Diode reset hours to 648 (27 days)
4/23/09	107	AMF	14363	MPL Azores install
4/30/09	104	FSPOL	11202	Pagosa install spare diode

Date	MPL	Site	Diode Hours	Comments
4/30/09	104	FSPOL	11202	F6-78499 fiber broken
8/10/09	104	Chile		Used laser diode installed
8/27/09	104	Chile		New laser diode installed
8/31/09	104	Chile		Try to align laser diode fiber
9/04/09	107	AMF		New laser diode installed
10/12/09	008	Chile		Remove MPL104, install MPL008
10/24/09	008	Chile		End RHUBC-II, MPL104, MPL008
12/01/09	409	ANL		Deploy MPL409 AMF2
01/21/10	008	ANL		Arrives at ANL from Chile. Misaligned laser
01/21/10	4103	ANL	40	MPL 4103 IDS first tested, OK
01/27/10	104	ANL		Ship to Sigma Space for repair
02/22/10	101	ANL	57	MPL 101 IDS first tested, OK
03/08/10	4103	ANL		To Sigma Space for polarizer repair
04/11/10	102	Manu		Installed new FSPOL upgrade
04/15/10	101	ANL		Shipped to Sigma Space for polarizer repair, forward to New York, Greenland
04/22/10	4103	ANL		Received from Sigma Space. Polarizer repair
05/04/10	4103	ANL	414	Deployed 484 in AMF2 enclosure
05/26/10	101	Greenland	1389	Installed
05/31/10	4103	ANL		Shutdown at 484 ship to RVCONN cruise
06/02/10	106	SGP		Removed from service at SGP
06/02/10	104	SGP	11640	FSPOL installed at SGP
06/14/10	4103	RVCONN		Deployed 06/14–18
07/02/10	4103	ANL		Deployed again at 484
07/29/10	4103	ANL		Diode dying with only 1673.1 hours
09/09/10	106	NSA		Shipped from Sigma Space, FSPOL upgrade
09/13/10	4103	MPL		Setup at Thunderhead V1 STORMVEX
10/06/10	4103		2368	Laser diode dying
10/21/10	4103			Sigma Space, liquid crystal damaged
10/23/10	008	AL		Old MPL set up at ALTOS in Alaska
11/02/10	105			MPL 105 FSPOL arrives at Manus
12/02/10	101	Greenland	5111	
02/02/11	104	SGP		Extreme water intrusion, ship to Sigma Space
02/04/11	107			From Azores to Sigma Space for FSPOL
04/21/11	101	Greenland	8453	
04/21/11	4012	Steamboat	6275	
04/21/11	106	NSA	4986 hours	ftdilog.txt: ReadData(): 02780F00 01BE00A8 19242 return=19242 0
04/21/11	108	Darwin	38053	
04/21/11	105	Manus	15571	ftdilog.txt: ReadData(): 024C0F00 019400A8 19242 return=19242 0
04/25/11	104	SGP	17540	Returned from repair
04/26/11	104	SGP		Switch from SigmaMPL 2.54 to 2.55
04/29/11	4103			Arrived at Sigma Space for laser/polarizer repair
05/02/11	106			Computer shipped from NSA to SGP
06/08/11	107			Shipped from Sigma Space to SGP, FSPOL upgrade
06/10/11	106			Returned to NSA, but not running due to SW problems
06/15/11	101	Greenland		New laser diode installed

Date	MPL	Site	Diode Hours	Comments
06/16/11	101	Greenland		Laser diode hours changed from 9235.4 to 36.0
06/16/11	102			At Sigma Space, repair completed. Ship to Pagosa Springs for India.
06/27/11	106			Working at NSA with SigmaMPL 4.06
08/23/11	107			Installed at Manus
08/31/11	108			Arrived at Sigma Space from Darwin, FSPOL upgrade
09/29/11	4103	Gan	6584	Setup at AMF2 Maldives
10/13/11	107	Manus	13064	Running SigmaMPL2010R1.1
10/13/11	104	SGP	21625	Has been running SigmaMPL 2.54
10/27/11	106	NSA		Software upgrade from 4.06 to 2010R1.1
01/12/12	409			Installed at Kent Co. Showgrounds near Detling, Kent, UK
02/07/12	102		114.5	Upgrade to FSPOL-IDS install at Nanital, Software SigmaMPL2010R1.1
02/14/12	409			Removed from Kent Co. Showgrounds near Detling, Kent, UK
05/02/12	108	Manus		Arrived at Manus, installing SigmaMPL2010R1.1
05/03/12	409	ANL		Setup at ANL 203 J160 for Demo
08/01/12	101	ANL		Returned to ANL from Greenland by Matt Shupe
08/01/12	107	Greenland		Installed at Greenland by Matt Shupe
09/27/12	4103	AMF2		MPL installed on Horizon Spirit
10/04/12	4103	AMF2		MPL removed and shipped to Sigma Space: SHG error open circuit
10/04/12	409			MPL installed on Horizon Spirit
10/10/12	105	Darwin		Upgrade installed at Darwin, IDS and SigmaMPL_2010R1.1
10/18/12	104	SGP	30485	MPL hard disk rebuilt
10/24/12	102	AMF1	3902	
12/13/12	4103	Spirit	10172.7	Installed on Spirit after repair
12/13/12	409	ANL		MPL removed from Spirit. Pump diode dead.
01/04/13	4103	Spirit	500	Reset pump diode hours to 500
01/21/13	4211	AMF1	952.4	AMF1 PVC TCAP
02/20/13	4212			Waiting at Sandia for Deployment to Oliktok
06/22/13	4103			Removed from Spirit for repair at Sigma Space
07/09/13	102	SGP		Arrived at SGP CF without native computer
07/09/13	104			Previous SGP MPL to be shipped to Sigma Space without computer
07/08/13	4211			Arrives at SGP for overlap correction
08/03/13	4103	Spirit	11642	Setup on Spirit for MAGIC
08/27/13	4103			Shipped out from dockside to Sigma Space again
09/01/13	4211			AMF1, awaiting deployment to Brazil
09/15/13	4212	OLI		Arrives at Oliktok and installed
09/30/13	101	ENA	20207	Setup at ENA Azores
01/01/14	4211	AMF1		Setup at AMF1 Brazil
01/03/14	107	Greenland	30279	
01/15/14	4103	AMF2	10602	Installed at AMF2 Finland
01/01/14	108			Removed from Manus. In transit to Sigma Space.
02/04/14	102	Manus		Replaced 108 at Manus
10/02/15	104			Sent for repair from SGP
11/10/15	107			Sent for repair from Greenland
11/27/15	4103	AMF2		Installed AMF2 at McMurdo
12/01/15	4211	AMF1		Taken down and returning from AMF1 (MAO)
01/21/16	102	SGP	13110.5	
01/21/16	105	WAIS		At McMurdo (WAIS)

Date	MPL	Site	Diode Hours	Comments
01/21/16	108	Greenland		Current location Greenland. Went from Norwegian icebreaker to ICECAPS before.
03/12/16	4211			At Sigma Space for repair. Came from AMF1 Brazil.
04/26/16	107	SGP		Running at SGP after repairs at Sigma Space
05/03/16	104	SGP		At SGP as a spare, came from Sigma Space
05/11/16	107	NASA Goddard		At NASA for possible deployment at Ascension Island (ASI) AMF1
06/27/16	4211	AMF1	24421.5	At ASI
03/21/17	107			Was not used for ASI, so NASA sent it to SGP
03/23/17	102	SGP		Switching between co-pol/cross-pol affected. Sending it to Sigma Space for LC evaluation.
03/23/17	104	SGP		Installed instead of MPL102
03/27/17	104	SGP		Electrical work at the GIF trailer caused power surge, affecting the laser. Send the MPL to vendor.
04/07/17	102			Evaluation: Detector, LC, Laser Controller replacement
04/12/17	104			Evaluation: Replacement of athermal telescope
04/12/17	105	AMF2		WAIS MPL arrived at LANL: Send to SGP
04/12/17	4103	AMF2		AWARE MPL arrived at LANL: To be used for MARCUS
04/20/17	4212	AMF3		Not switching: Sent to Sigma Space for repair. LC replacement, Equivalent to new MPL laser replacement
05/08/17	105			Arrived at SGP from LANL (WAIS): keep as a spare
07/07/17	104	OLI		Arrived directly from vendor
07/17/17	4103	AMF2		LANL for beta test: Degraded LC performance. Shipped to Sigma Space for LC replacement and alignment.
08/15/17	4103	AMF2		Arrived at LANL for MARCUS pack-up. No time for testing.
10/03/17	105	NSA		Sent from SGP to replace 106, as MPL106 is being sent for investigating the cause of high depolarization values.
11/27/17	4212			Sent to replace 4103 at MARCUS due to high depolarization value problem.
03/02/17	101			Received at Sigma Space, sent from ENA, for evaluation
09/23/18	4211	AMF1		Running at COR
11/21/18	4212	SGP	34542.3	Replaced 107 at SGP
11/21/18	107			Shipping to Sigma Space: unrealistic R^2 corrected signal nighttime peak
11/30/18	106			Evaluation: replace laser controller, athermal telescope, detector, LC module repair
11/30/18	101			Evaluation: replace laser, telescope, detector, LC module repair
02/18/19	4103	AMF1		Received at COR, replacing 4211 that was misaligned and is being sent for evaluation.
03/21/19	101	AMF2		At LANL for MOSAIC beta test.
03/28/19	106			Received at SGP to be kept as a spare.
04/09/19	106	AMF1		Sent to LANL for COMBLE
05/13/19	4211			Arrived at Sigma Space
08/06/19	4103	AMF1		At COMBLE S2 (Bear Island), operating in its enclosure.
09/10/19	101	AMF2		Arrived for MOSAIC. Did not pulse (laser immediately killed the diode). Afterpulse dramatically different from one done at Sigma Space. Dark black spot in the beam: laser affected. Sending it back to vendor.
09/14/19	106	AMF2		Arrived for COMBLE but diverted and sent to MOSAIC.

Date	MPL	Site	Diode Hours	Comments
12/06/19	107	AMF1		At COMBLE (ANX M1)
02/11/20	4211			Repaired MPL arrived at SGP. Keep as a spare.
02/18/20	4212	SGP	41469.8	Frequent energy level drops. Replaced the diode.

4.0 Near-Real-Time Data Plots

Data collected by MPLs can be viewed in near-real time through the Data Quality Office's (DQO) Quick Plot Browser via selecting the desired site and "mpl" under the instrument class.

5.0 Data Description and Examples

The raw binary data produced by the MPL contains the signal return in the co-pol and cross-pol channels. These are ingested along with various correction files necessary for Normalized Relative Backscatter (NRB) calculation and made available to users as a "b1"-level data product. This data product can be accessed through the ARM Data Discovery Tool with the *SIDmplpolfsFID.b1* datastream name structure, where SID = Site ID (e.g., sgp) and FID = Facility ID (e.g., C1).

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

The MPL has two measurement channels that record backscatter signals up to 20+ km. The primary quantity derived from this signal is the lowest detected cloud base in meters, which is a value-added product (VAP).

Additional quantities possible through post-processing of the raw signal return include the NRB profile at 532 nm. From the relative backscatter profile, other data products are possible, including multiple cloud decks, cloud and layer boundaries, cloud ice/water, and aerosol extinction and backscatter profiles.

Definition of Uncertainty

The uncertainties in reported cloud base height have several sources. There is an inherent calibration uncertainty of the timing electronics of about 2%. This translates directly into an uncertainty of ± 2% for all reported distances.

Also, the measured lidar profiles are collected in discrete "range bins" with finite width. Reported cloud heights are centered within the range bin, so cloud base heights will have an uncertainty of ±1/2 the range resolution. Early MPL systems deployed at SGP and TWP C1 had a range resolution of 300 meters. ARM MPL systems are currently operating with 15-m resolution.

Several other uncertainties are more difficult to quantify. The MPL is an eye-safe lidar, and as such, it transmits a very low-power laser beam, typically less than ~25 mW at 532 nm. Thus, it is subject to signal-to-noise limitations in conjunction with solar background noise. Moreover, the laser beam is attenuated or extinguished as it passes through the atmosphere. These two effects combine to make detection of high, thin clouds more difficult during the day. Furthermore, over time laser systems degrade and produce less powerful pulses, so the sensitivity of the MPL will depend on the health of the laser system in the MPL. In addition to these measurement limitations, there are other uncertainties that are difficult to quantify. Exactly "what is a cloud" is difficult to define. Algorithm differences can yield biases in reported cloud base height: while one algorithm may identify a particular atmospheric structure as being a "cloud", another algorithm may not. Thus, algorithm sensitivity is also a difficult uncertainty to quantify.

5.1.2 Dimension Variables

Not applicable to this instrument.

5.2 Annotated Examples

Not applicable to this instrument.

5.3 User Notes and Known Problems

Not applicable to this instrument.

5.4 Frequently Asked Questions

What MPL datastream should I use for clouds?

Use ARSCL or NRB VAP profiles (MPLNOR). If neither is available, the b1-level MPL measurements can be used for NRB calculation detailed by Welton et al. 2001 and Campbell et al. 2002.

What MPL datastream should I use for aerosol products?

ARM MPL aerosol retrievals are currently in development but are not operationally available. For limited periods, aerosol products from the ARM MPL at SGP are available from NASA's MPLNET. For qualitative indications of aerosol, the normalized backscatter profiles from MPLNOR are excellent indicators of aerosol layers and relative abundance. Use of b1-level MPL datastreams for aerosol detection is only advised if significant corrections to the data including overlap, dead-time, and afterpulse corrections are taken into account.

What is the lowest cloud the MPL can detect?

The minimum detection height of the MPL is on the order of 150 m. Below that the signal is swamped by afterpulse.

6.0 Data Quality

6.1 Data Quality Health and Status

The Data Quality Office (DQO) website has links to several tools for inspecting and assessing MPL data quality:

- DQ-Explorer
- DQ-Plotbrowser
- DQ-Zoom
- NCVweb: Interactive web-based tool for viewing ARM data

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

QC frequency: Monthly

QC delay: 1 week

QC type: Graphical plots

Inputs: Raw data

Outputs: Processed backscatter profiles

Daily data quality monitoring of the MPL at all ARM sites mainly consists of visual inspection of vertical time sections of backscattered signal.

6.3 Data Assessments by Site Scientist/Data Quality Office

All data quality and most site scientist techniques for checking have been incorporated within DQ Explorer.

6.4 Value-Added Products

Many of the scientific needs of the ARM user facility are met through the analysis and processing of existing data products into value-added products (VAPs). Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the facility. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces "best-estimate" VAPs.

Two VAPs currently use the raw MPL datastream. Whenever possible, the following value-added products should be used in preference to the raw or b1-level MPL datastream.

- **MPLNOR**: "MPLNOR" stands for *MPL normalized*. It produces "normalized" backscatter profiles (in arbitrary units) with all known instrument artifacts removed. To improve the signal-to-noise ratio, MPLNOR applies further temporal and spatial averaging. It also reports up to three layers of clouds along with cloud base and cloud top when possible. Both a "sensitive" and "robust" cloud mask are provided where the "robust" cloud mask is simply the "sensitive" mask with some filters applied to remove false positives.
- **ARSCL**: "ARSCL" stands for *Active Remotely Sensed Cloud Locations*. It represents a composite product combining measurements from ceilometers, lidar, and radar. Lidar and radar measurements are complementary in that lidar are more sensitive to smaller particles often found in cirrus or low-water-vapor clouds. However, radar can penetrate multiple cloud decks that are impossible for lidar to penetrate. Thus, this composite product provides the best of both instruments and is currently ARM's last word on cloud detection.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The MPL consists of four main components: (1) a computer, (2) a dedicated data acquisition and lidar control system, (3) a diode-pumped Nd-YLF laser system, and (4) a co-axial transceiver for transmitting the laser pulses and detecting the collected photons. A description of each component follows.

1. **Computer**: Currently, laptops are used with all ARM MPL systems. All laptops use the CORE-PC operating system developed by ARM.
2. **Lidar control system**: The lidar control system, custom produced by Sigma Space, provides conditioned power to the photon detector and laser energy monitor. It contains an integrated A/D converter for reporting of vital system parameters to the instrument PC. It also contains the range-selectable multi-channel scalar that accumulates the range-resolved backscatter profiles.
3. **Laser-diode-pumped Nd-YLF laser system**: The laser power supply provides continuous wave (CW) laser diode infrared pump radiation to the Nd-YLF laser head within the transceiver. The power supply also controls the pulse repetition rate of the Nd-YLF laser head incorporated into the MPL transceiver (described below). Originally, all MPL systems used Spectra Physics lasers (model 7300 or "R-Series"), but as these lasers were discontinued, the lasers have been supplied by Photonics, Inc.
4. **Co-axial transceiver**: The "transceiver" serves as both transmitter of the outgoing laser pulses and receiver of backscattered light. Approximately 1.0 watt of infrared CW pump radiation is converted to about 25 mW pulses of green laser light (532 nm) at 2500 Hz by the Nd-YLF laser head with non-linear optical frequency doubler. The pulses of green light are passed through a linear polarizing beam splitter, a depolarizing wedge, and expanded to fill an 8" Celestron telescope. At present, all ARM MPL systems have incorporated the multi-channel scanner into the transceiver package. The laser power supply, made by Photonics, Inc. remains separate from the transceiver.

The detection optics begins with the same 8" Celestron telescope. Returning photons incident on the telescope are collected and pass through the depolarizing wedge. About half of the collected photons pass through the polarizing beam splitter cube and half are reflected. Light passing through the beam splitter is collimated and passed through two narrow-band interference filters (0.27 nm fwhm) in order to reject most of the ambient light and is ultimately focused onto a photon-counting avalanche photodiode (APD) module.

7.1.2 System Configuration and Measurement Methods

The MPL is configured to operate autonomously in an unattended manner 24 hours a day, with 10-second averaging time and 15-m vertical resolution. Standard ARM deployments orient the MPL vertically (or slightly off vertical).

7.1.3 Specifications

Wavelength of laser pulse: 532 nm

Length of laser pulse: ~10 ns = 3 m

Range resolution (height interval): 15 m

Maximum range for cloud base height: 18 km

Typical averaging: 10 sec

7.2 Theory of Operation

The principle is straightforward. A short pulse of laser light is transmitted from the telescope. As the pulse travels along, part of it is scattered by molecules, water droplets, or other objects in the atmosphere. The greater the number of scatterers, the greater the part scattered.

A small portion of the scattered light is scattered back, collected by the telescope, and detected. The detected signal is stored in bins according to how long it has been since the pulse was transmitted, which is directly related to how far away the backscatter occurred.

The collection of bins for each pulse is called a profile. A cloud would be evident as an increase or spike in the backscattered signal profile, since the water droplets that make up the cloud will produce a lot of backscatter.

7.3 Calibration

7.3.1 Theory

Little calibration is necessary for cloud-base height determination. To fix the distance scale, it is necessary to use a calibrated-pulse generator capable of producing a trigger pulse and a second delayed pulse with an accurately known time lag. The two pulses are used to mimic a transmitted laser pulse and detected backscatter pulse with time delay relating to a simulated distance.

Absolute calibration of the magnitude of the lidar signal is much more difficult. The following instrument-level corrections are required:

1. **Dead-time correction**: A correction to account for the detector saturation effect when high count rates occur (strong signal return). A lookup table is provided by the vendor to correct for this detector non-linear response, which is unique for each lidar/detector.
2. **Afterpulse correction:** Afterpulse is the "detector noise" induced by the laser firing. It occurs when internally scattered laser light saturates the detector at the beginning of each sampling period and creates a near-field blind zone. The afterpulse includes the detector "dark counts"/"dark noise", which is the instrument noise related to thermal effects.
3. **Background subtraction**: Background noise due to sunlight at 523 nm.
4. **Range-squared correction**
5. **Overlap correction:** overlap correction as a function of range, to account for the loss in the near-field receiver efficiency.
6. **Energy-monitor normalization.**

Even after these various corrections are applied, the overall system transmittance is only coarsely known. Determination of this overall system calibration is typically obtained by comparison against other external measurements, modeled results, or both.

Figure 1 shows an example of the co-pol and cross-pol profiles (top and middle panels) on 2020-03-04 at the SGP Central Facility after applying all corrections discussed above. The bottom panel shows the linear depolarization ratio. A cloud layer is evident at 6−8 km expressed with large (shown in red) NRB values.

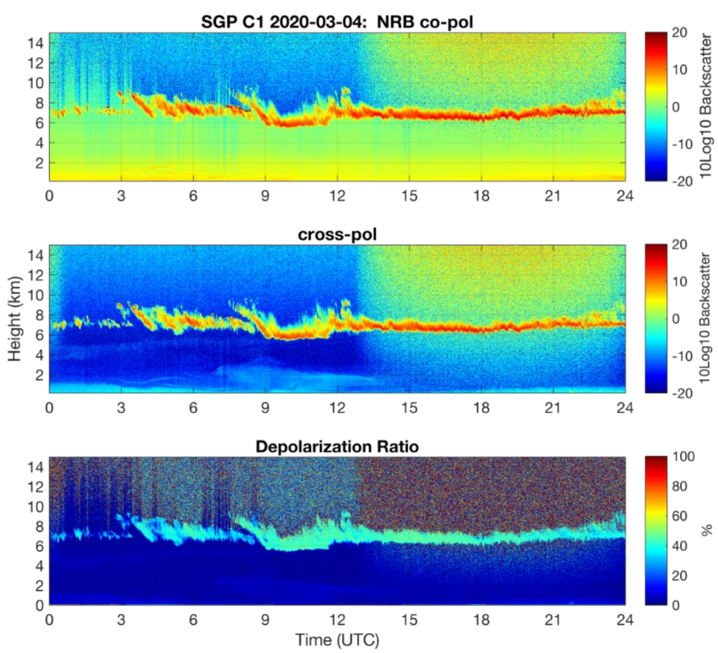

Figure 1. An example of the co-pol and cross-pol Normalized Relative Backscatter (top and middle panels respectively) as well as the profile of linear depolarization ratio (bottom panel) at the SGP Central Facility.

7.3.2 Procedures

All the above-mentioned corrections are currently being provided in the b1-level data.

- The dead time corrections are supplied by the vendor with every new detector.
- Afterpulse and dark count correction procedures are performed by the site operators on a quarterly basis; these are then validated and uploaded for the ingest by the mentor.
- The overlap:
  - The overlap calibration has historically been performed by the vendor, so new overlap corrections were available only after an instrument was evaluated, tested, and repaired at the Sigma Space facility. However, SGP is also equipped with horizontal overlap calibration capability, which has occasionally been performed by the mentor and the site operators when an MPL is available at SGP.
  - ARM has added the in-field overlap calibration capability for ARM mobile facility (AMF) deployments (which were prioritized due to the accessibility and time constraint issues of these deployments) with the use of wide field receivers (WFR). The WFRs are much like the receiver inside the MPL, but with much wider field of view. These are manually operated, center-mounted receivers that sit on top the regular MPL telescope and sample the same column of the atmosphere as the MPL. The WFR measurements are collected simultaneously with a second data channel, which is then used to calibrate the MPL for overlap. The in-field overlap calibration is currently planned to be performed on an “as-needed” basis.

7.3.3 Routine and Corrective Maintenance Documentation

Little maintenance is required other than routine cleaning of the viewport window and gentle cleaning of dust from the telescope. Occasionally, the software or computer may lock up, so visual confirmation that the program is operating, that the clock is updating, and that the displayed measurement agrees with reality are also required.

Both the co-pol and cross-pol signals are displayed on the local MPL computer. The low-level signal should usually show a marked difference between the co- (green) and cross- (red) polarized signal returns because there is little cross-polarized signal from aerosols or water droplets. For many clouds, the red- and green-colored traces will often become similar, indicating that the signal source is ice instead of water. If there is little difference between the two signal returns for all heights and several days, there may be a problem with the polarizer, and the mentor should be notified. The laser current should usually be between 0.5 and 1.0 amp, and the laser energy should be between 2 and 7 μJ.

Daily and monthly preventative maintenance procedures are designed by the mentor and available to the site operators at all ARM sites.

7.4 Glossary

See the ARM Glossary.

7.5 Acronyms

lidar: light detection and ranging

Also see the ARM Acronyms and Abbreviations.

8.0 Citable References

Campbell, JR, DL Hlavka, EJ Welton, CJ Flynn, DD Turner, JD Spinhirne, and VS Scott. 2002. “Full-time Eye-Safe Cloud and Aerosol Lidar Observation at Atmospheric Radiation Measurement Program Sites: Instruments and Data Processing.” *Journal of Atmospheric and Oceanic Technology* 19(4): 431–442, https://doi.org/10.1175/1520-0426(2002)019<0431:FTESCA>2.0.CO;2

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