Micropulse Lidar Data Sets and Initial Observations at Nauru Island

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Introduction

Full-time atmospheric profiling via active remote sensing greatly enhances the complete picture of cloud and aerosol complexes observed at Atmospheric Radiation Measurement (ARM) facilities. The current array of such ARM owned and operated instruments include the Millimeter-Wavelength Cloud Radar (MMCR), Belfort Laser Ceilometer (BLC), Vaisala Ceilometer (VLC), Raman Lidar (RL), and Micropulse Lidar (MPL) (Spinhirne 1993). Costs and logistical constraints have so far limited installing each of these systems at all four central sites. Only the MPL is present at each and additionally planned among the first instruments deployed to a third Tropical Western Pacific (TWP) site. The MPL benefits from an inexpensive, ruggedized, eye-safe design ideally suited for tractable remote field deployment and continuous operation. The significant eye-safety feature is achieved by expanding a 1.0 W Nd:YLF laser (523 nm) through a 0.2-m diameter Cassegrain telescope at high pulse repetition frequencies (2500 Hz) (Spinhirne et al. 1995). The MPL therefore requires no operational supervision. Although relatively low-powered, systems are capable of detecting all significant tropospheric cloud and aerosol layers via a high quantum efficiency Geiger-mode Avalanche Photo Diode detector (GAPD), a unique optical design providing suitable geometric signal compression, and appreciable pulse summation limiting the effects of solar background. Additionally, a receiver field of view on the order of 100 μrad effectively eliminates the significance of multiple scattering.

In contrast to their analogous counterpart radar, lidar systems operate at wavelengths capable of the routine detection of smaller atmospheric particulates and hydrometeors such as cirrus (Sassen 1995). Though more susceptible to attenuated range-limiting effects from water cloud and those composed of dense ice, their ability to characterize many range-integrated optical parameters, record particulate layer structure and position, and infer cloud phase or aerosol composition (Sassen 1991; Ackerman 1998) finds them nearly indispensable. However, delicate, thermally sensitive components and intricate optical alignment procedures ultimately impact lidar operations over temporally extended periods. Indeed, most relevant lidar studies have commonly resulted from short field projects such as FIRE (First ISCCP [International Satellite Cloud Climatology Program] Regional Experiments) and ARM intensive observation periods. The ARM MPL observing program represents the first continuous global lidar study known within the community. This presentation discusses the development and current status of the six past and present ARM MPLs and their data sets. Existing value added processing (VAP) routines and planned products are also reviewed. Finally, data sampled from the latest system addition at the new Nauru Island Atmosphere Radiation and Cloud Station (ARCS) are presented.

System Evolution, Timeline, and Current Status

The prototype MPL (unit 00) was constructed for ARM at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in 1993, with subsequent systems built by Science and Engineering Services (SESI) of Burtonsville, Maryland. Original unit data acquisition cards featured maximum 300-m low-range resolution (unit numbers 00, 02, and 03, to be referred to as LR), while new generation systems have increased to 30 m (54, 58, and 59, to be referred to as HR). Physical system design has also progressed. The prototype design, kept through the 02, 03, and 54, cast a Cassegrain telescope atop a widened optics box acting as unit base. New generation systems compress the optics within a tube-like canister sized to mount at the base of the telescope. The connected unit then pivots within two mounting posts allowing for adjustable viewing angle.

Spatially averaged backscattered photon counts are averaged over a user-defined period and written (as individual ‘shots’) to the local storage disk in a simple NASA-developed binary format concatenated into hourly files. An information header precedes each shot profile denoting significant system diagnostics and housekeeping details such as time stamp, pulse energy monitor, and component temperatures. Its sum byte size varies by system version; unit 00 use a 25-byte header, subsequent LR units use 36 bytes and HRs employ 44. Following the header, shots are broken into range-resolved counts via successive four byte segments taking the form:

$$n(r) = \frac{b(1)*256^3 + b(2)*256^2 + b(3)*256 + b(4)}{1.0x10^8} \quad (1)$$

Using a maximum effective sampling range of 60 km, LR systems can inspect as many as 200 range bins (800 bytes) and HRs 2001 (8004 bytes). Consequently, a complete day of LR data with 60 s sampling frequency at such a resolution totals nearly 1.2 MB of data, while corresponding HR systems record slightly over ten times this amount. Hourly binary files are stored in the ARM archive along with simultaneously rewritten netCDF formatted files. The flexible and arguably more efficient latter structure allows for the addition of supplementary information regarding the lidar (e.g., viewing angle, GAPD serial number, and correction factors), which are required in post-processing (Campbell et al. 1998).

Table 1 lists all of the past and present ARM MPLs, their dates of operation and temporal and range resolution settings. Of the six systems, MPL00 now resides at GSFC, MPL02 at Pacific Northwest National Laboratory (PNNL), and the remaining four at their noted operating sites. Discontinuities in listed performance periods are the result of repairs. It is worth mentioning that servicing instruments at the tropical sites can be significantly delayed by their remote location. The Manus Island MPL03 suffered a six-month downtime in early 1998, and the MPL59, which suffered a GAPD failure in January, should be reinstalled by April. With the exception of the latter, all are currently functioning nominally.

Table 1. A listing of the six MPL systems that have operated at ARM facilities, including dates, range, and temporal shot averaging resolution.

Unit	Site	Dates	ΔV	ΔT
00	SGP	12/93 - 3/96	300 m	60 s
02	SGP	1/96 - 8/98	300 m	60 s
03	Manus	2/97 - 11/97 4/98 - present	300 m	60 s
54	SGP	8/98 - 11/98 1/99 - present	30 m	30 s
58	NSA	3/98 - present	30 m	30 s
59	Nauru	11/98 - 1/99	30 m	30 s

NSA = North Slope of Alaska.
SGP = Southern Great Plains.

Value Added Processing Data Products

A sum total of nearly ten years of raw MPL data exists within the ARM archive. The GSFC lidar group has served as an advisor on data processing algorithm development and system calibration and alignment techniques. ARM currently runs one VAP routine on raw MPL data concatenating the results of two algorithms: normalized relative backscatter (NRB) values allowing users to yield case-by-case attenuated backscatter profiles (shot-by-shot, or in group averages) after calculating the case-dependent calibration constant, and multiple cloud boundary heights calculated from individual shot NRB vertical structure (Campbell et al. 1998). Additionally, cloud base height files produced at GSFC using the Scott-Spinhirne algorithm (Sc/Sp) discussed by Clothiaux et al. (1998) are collected by the ARM data center for distribution. MPL data can be used, though to yield numerous other cloud and aerosol radiative and optical parameters including scattering cross sections and optical thicknesses, planetary boundary layer heights and aerosol extinction profiles. Spinhirne et al. (1999) detailed such optical properties observed during a dense biomass burning event at Manus Island during late summer 1997, and efforts are now under way to develop automated cirrus cloud emittance and optical depth retrievals from the same site combining MPL and radiometric measurements (i.e., lidar/radiometer [LIRAD]). The prospects of automated aerosol optical property retrievals are specifically addressed in a separate presentation at this conference (Spinhirne et al. 1999). Such a routine appears likely to be implemented soon, though the success of any algorithm is ultimately dependent on the absolute calibration of the system. System optical alignment inconsistencies and GAPD diode-noise considerations have offered varying degrees of challenge to data post-processing. In particular, aerosol optical calculations are critically dependent upon a stable, accurate system alignment. Over the past year, two informal MPL workshops have taken place at the GSFC involving ARM engineers to address these issues. It is optimistically believed that current and future instrument operations will be free of most technical shortcomings, which have previously affected systems. Table 2 breaks down each of the data sets listed in Table 1 addressing pertinent system notes, the status of related VAP products, and the feasibility of aerosol-related calculations.

Table 2. A listing of MPL data set availability within the ARM archive by system number, including temporal and range resolution settings. The three VAP routines denote the NRB, multiple cloud base height (MCBH) and Scott/Spinhirne cloud base height algorithm products. The final column notes the relative feasibility of aerosol related study. 'Yes' answers with a '*' correspond to data available only in beta-test mode at this time. 'Pending' files denote those where processing will take place shortly.

Unit	Dates	ΔV	ΔT	NRB VAP	MCBH VAP	Sc/Sp VAP	Aerosol
00	12/93 - 3/96	300 m	60s	No	Testing	Yes	No
02	1/96 - 8/98	300 m	60s	Yes	Yes	Yes	Most
03	2/97 - 11/97 4/98 - present	300 m	60s	Yes*	Yes	Yes*	Most
54	8/98 - 11/98 1/99 - present	30m	30s	Yes*	Yes*	Yes*	Most
58	3/98 - present	30 m	30s	Pending	Pending	Pending	Some
59	11/98 - 1/99	30 m	30s	Pending	Pending	Pending	Yes

Initial Observations at Nauru Island

MPL59 became the latest group addition upon its installation at the Nauru Island ARCS in early November 1998. Figure 1 displays a five-day image of overlap corrected backscatter returns from mid-January. A consistent cirrus deck is observed with tops approaching 19 km, presumably corresponding with the local tropopause height, and thicknesses on the order of 2 km. At first glance, these values are greater in magnitude than those seen at Manus Island, which is noteworthy given its further proximity from a land surface capable of producing boundary-layer instabilities and convection routinely responsible for cirrus generation. Figure 2 plots an hour-long averaged vertical profile on January 4, 1999, during nighttime hours. A column-averaged extinction-to-backscatter ratio near 30 was calculated, which agrees well with the theoretical value for an ocean climate found by Ackerman (1998). Whereas an independent measurement of aerosol optical depth (AOD) was not available for this period (routinely required to solve the MPL calibration value), an iterative 'best-fit' routine was implemented producing an MPL-measured AOD of 0.065. Again, this value seems reasonable given the shallow boundary layer topped near 2 km and the lack of pollutant advection from any nearby urban source. Unfortunately the GAPD failed on this system in late January 1999, though maintenance scheduled to be completed in early April should restore on-line status by May.

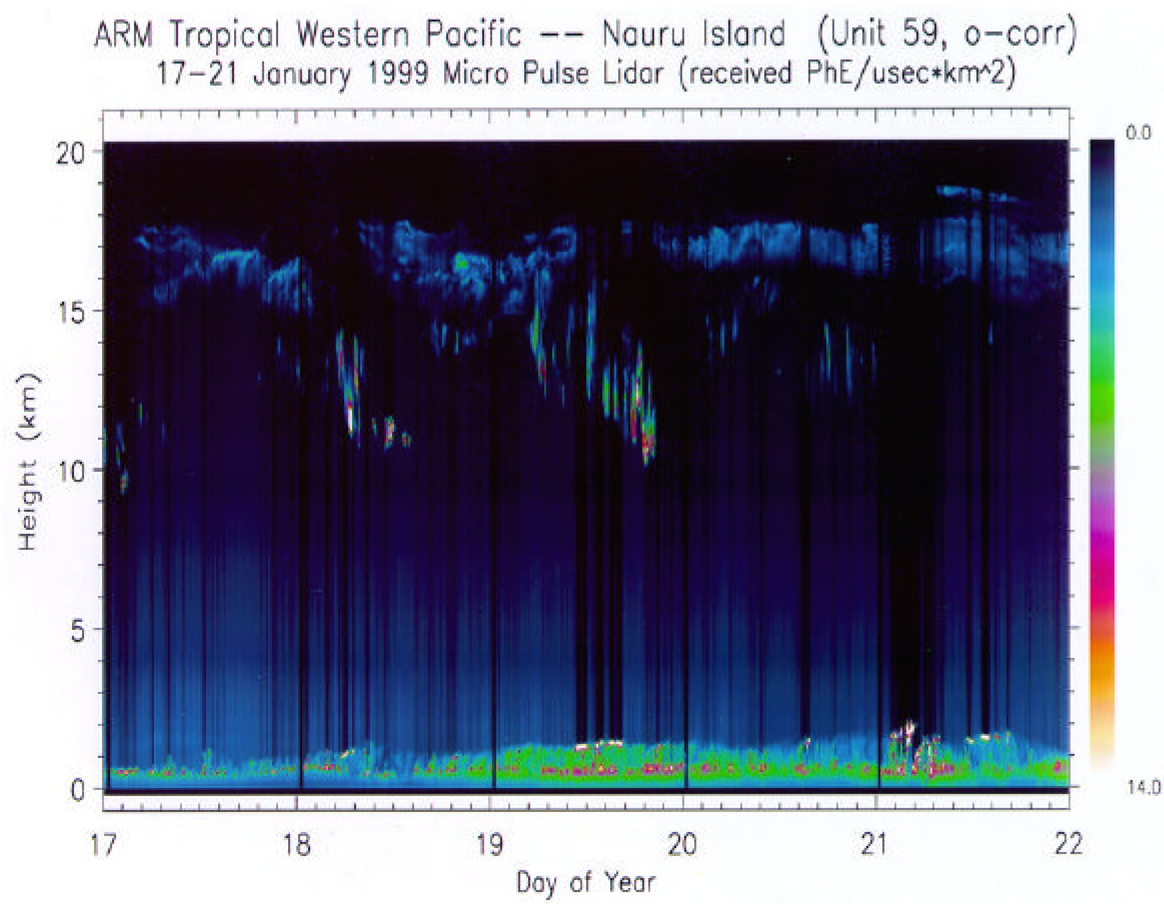

Figure 1. Overlap and deadtime corrected MPL raw backscatter time versus height quickplot at the Nauru Island ARCS from January 17-21, 1999.

Conclusions

MPL data sets provide crucial continuous optical observations at the ARM sites. The many uses of the data continue to offer diverse avenues of temporally extended atmospheric research. Algorithm and calibration techniques developed by GSFC and ARM are making real-time and historical data sets available through the ARM Data Center. Additionally, the prospects for further VAPs encompassing aerosol research appear good. The addition of a second TWP system in the past year, with a third planned as well, will contribute greatly to the characterization of cloud and aerosol structure in that region.

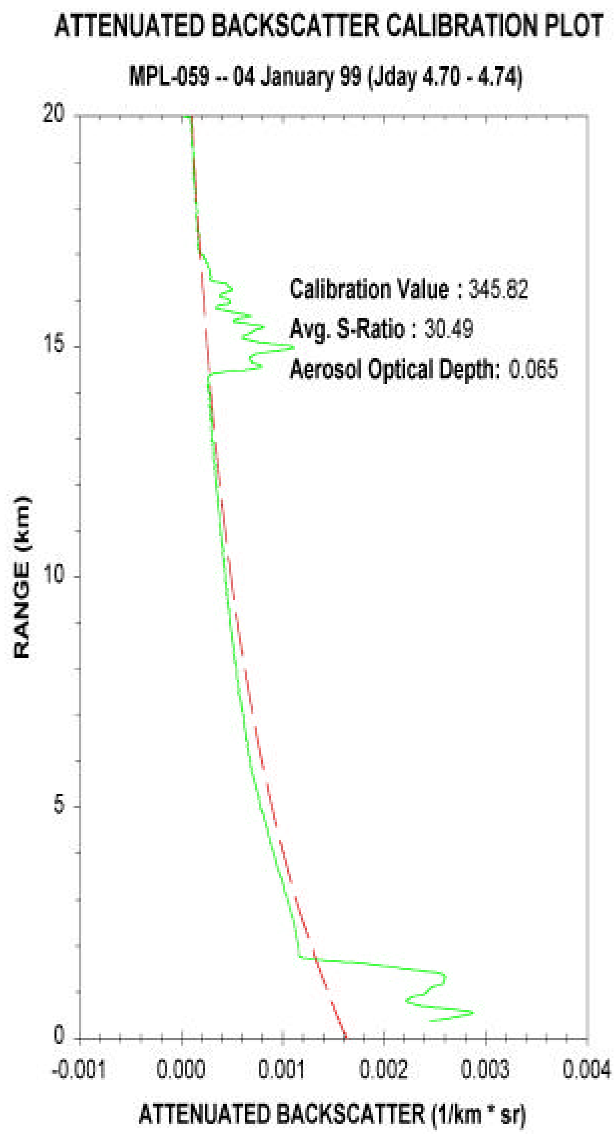

Figure 2. 60-minute average of MPL-attenuated backscatter (solid) versus range, compared to a theoretical Rayleigh scattering (dashed) profile for January 4, 1999, at Nauru Island.

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