4.2 AUTONOMOUS, FULL-TIME CLOUD PROFILING AT ARM SITES WITH MICRO PULSE LIDAR

James D. Spinhirne*
NASA Goddard Space Flight Center, Greenbelt, MD

James R. Campbell and Dennis L. Hlavka
Science Systems and Applications, Inc., Lanham, MD

V. Stanley Scott
NASA Goddard Space Flight Center, Greenbelt, MD

Connor J. Flynn
Pacific Northwest National Laboratories, Richland, WA

1. INTRODUCTION

Since the early 1990's technology advances permit ground based lidar to operate full time and profile all significant aerosol and cloud structure of the atmosphere up to the limit of signal attenuation. These systems are known as Micro Pulse Lidars (MPL), as referenced by Spinhirne (1993), and were first in operation at DOE Atmospheric Radiation Measurement (ARM) sites. The objective of the ARM program (Stokes and Schwartz 1994) is to improve the predictability of climate change, particularly as it relates to cloud-climate feedback. The fundamental application of the MPL systems is towards the detection of all significant hydrometeor layers, to the limit of signal attenuation. The heating and cooling of the atmosphere are effected by the distribution and characteristics of clouds and aerosol concentration. Aerosol and cloud retrievals in several important areas can only be adequately obtained with active remote sensing by lidar. For cloud cover, the height and related emissivity of thin clouds and the distribution of base height for all clouds are basic parameters for the surface radiation budget, and lidar is essetial for accurate measurements.

The ARM MPL observing network represents the first long-term, global lidar study known within the community. MPL systems are now operational at four ARM sites. A six year data set has been obtained at the original Oklahoma site, and there are several years of observations at tropical and artic sites. Observational results include cloud base height distributions and aerosol profiles. These expanding data sets offer a significant new resource for cloud, aerosol and atmospheric radiation analysis. The nature of the data sets, data processing algorithms, derived parameters and application results are presented.

2. OBSERVATIONS

The basis of the MPL design is the use of lasers with high pulse repetition frequencies (PRF) and low pulse energies. When highly efficient optics, filters and detectors are used, it is possible to obtain profiling of all significant cloud and aerosol structure of the atmosphere with eye safe pulse energies in a compact, low power instrument design. The design for the instruments, which operate at 523 nm, has been described previously by Spinhirne (1995). A diode pumped Nd:YLF laser operating at 2.5 kHz pulse repetition rate is used. The original instrument had a pulse power of 2 μJ. The 8 μJ energy of the current instruments are still well within the estimated 25 μJ eye safe limit for their 20 cm aperture. In addition to the compact transmitter-receiver unit, a system is composed of a small power supply and a PC computer data system. Instruments require no operational supervision, only routine maintance. Current instruments record data at a vertical resolution of 30 m and with one or half minute sampling. Higher sampling is possible but is limited due to data volume considerations. In addition to the ARM MPL instruments, over 20 other MPL systems have been built.

MPL instruments currently operates at each of the four ARM sites (southern Great Plains (SGP), tropical western Pacific (TWP) sites at Nauru and Manus Islands, and Barrow, AK (NSA)). Table 1 lists all of the past and present ARM MPL systems, their range and temporal averaging resolution settings, and the status of relevant cloud datasets.

3. DATA ANALYSIS AND RESULTS

For clouds, cloud presence, cloud base height, cloud top height (thin clouds), multiple cloud layers (thin or broken clouds), and profiles for cloud scattering cross section and cloud optical thickness (thin clouds) are being processed operationally, or techniques for processing are nearing development. Our lidars routinely detect relatively thin cloud (ice clouds and some stratus), to which they are uniquely sensitive, which cloud radars and ceilometers commonly fail to observe. For aerosol scattering, the retrieved parameters are cloud cleared aerosol scattering profiles, including stratospheric aerosol layers (night only). Planetary boundary layer (PBL) height may be obtained in cases where it is defined by the aerosol structure. Aerosol optical thickness retrievals are also possible.

* *Corresponding author address:* James Spinhirne, NASA Goddard Space Flight Center/912, Greenbelt, MD 20771; e-mail <spinhirne@gsfc.nasa.gov>.

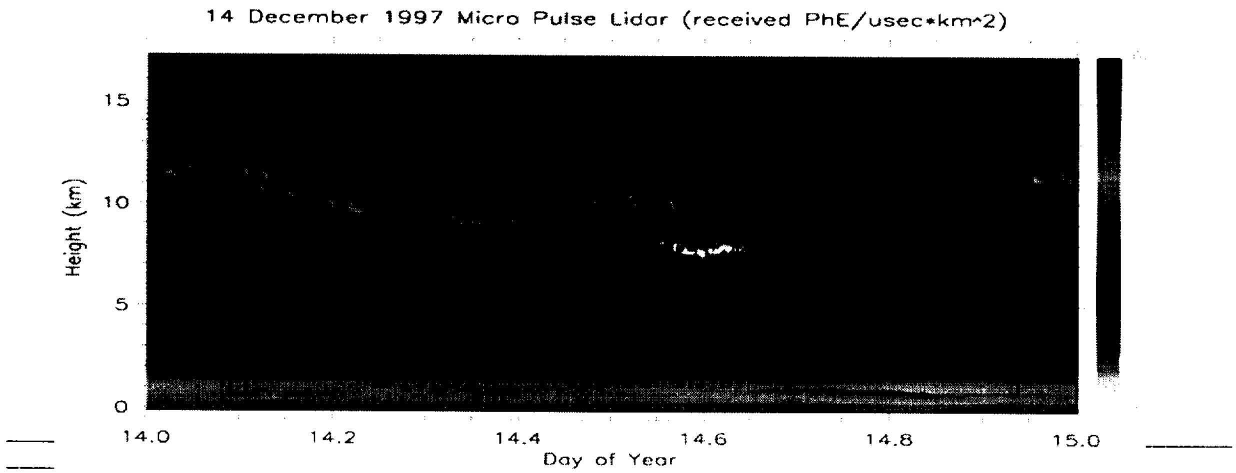

FIG. 1. MPL data for a single day of operation showing clouds and aerosol structure.

The image in Fig. 1 is an example of MPL data for one day. The PBL aerosol structure is clearly defined. Thin cirrus also is easily identifiable. Correlation of cloud and aerosol structure has been observed in many of these images. The initial procedure in data processing is to remove instrument factors. There are several corrections that are needed. The detector system is photon counting and a signal correction is required for photon coincidence at high count rates. At low altitude there must be a correction for lidar receiver factors. This so-called overlap correction is calculated using a horizontal MPL profile which allows for the assumption that the aerosol backscatter is constant for a significant range. The overlap correction ceases to exist beyond some range r_0. In a plot of the natural log of the range-corrected signal verses range, the overlap corrected signal will follow the slope of the signal beyond r_0 while the original signal decays in the near range. The overlap correction has been routinely applied to recent data.

In order to make it possible to browse data and see atmospheric structure, bi-weekly atmospheric lidar profile images are produced for ARM site data. Images are created using ten minute averages for the lidar return profiles from 0 km to 15 km. The images can be accessed through our Cloud and Aerosol Lidar web page by opening the URL: http://virl.gsfc.nasa.gov.

A cloud presence and cloud base height retrieval has been applied to all ARM MPL data and results are available from the web site or the ARM data system. Value added processing (VAP) within the ARM Data Center apply post-processing algorithms to raw data. Two such routines are applied to MPL data to calculate cloud boundary heights. The first was developed by Scott and Spinhirne (SCSP), and explained by Clothiaux et al. (1999). The SCSP algorithm is a basic thresholding algorithm, and yields cloud base heights. The second algorithm is a multiple cloud boundary search routine (MCBH) developed by Campbell et al. (1998). Depending on the level of signal attenuation, up to five cloud layers are reported. With some exception, all of the ARM datasets have been processed through these algorithms, and results are available to the community through the ARM archive. The current cloud recognition algorithm is based on a threshold analysis that is adjusted for the expected signal

SITE	UNIT	DATES	ΔV	ΔT	MCBH VAP	SCSP VAP
Southern Great Plains	00	12/93 - 3/96	300 m	60s	Testing	Yes
	02	1/96 - 8/98	300 m	60s	Yes	Yes
	54	8/98 - 11/98 1/99 - present	30m	30s	Yes*	Yes
Manus Island	03	2/97 - 11/97 4/98 - 7/99	300 m	60s	Yes	Yes
	73	7/99 - present	30m	30s	Yes*	Yes*
Nauru Island	59	11/98 - 1/99 4/99 - present	30 m	30s	Yes	Yes
Barrow, AK	58	3/98 - present	30 m	30s	Yes*	Yes*

Table 1. Listing of ARM MPL systems by location, date of operation, maximum range resolution, and temporal average setting. Also noted is the availability of value added processing algorithm cloud height information for the individual datasets within the ARM data archive. The two routines are described in the text.

noise. The cloud detection differentiates one minute profiles that are clear or cloudy and thus gives a very accurate measure of cloud fraction. The limiting factor is the definition of how low of scattering cross section is considered a cloud.

Fig. 2 shows results from the cloud recognition algorithm. Cloud base distributions are shown taken from one minute average profiles over a period of nearly 2.5 years. The distributions show the predominance of clear sky, which is well over 50 percent, with low clouds the most frequently observed clouds. Beam-blocked conditions, where condensation forms atop the MPL transmitting window causing immediate pulse attenuation, affects approximately 8% of the sample period. Otherwise, cloud is detected nearly 60% of the time. Of note, the first range bin contains cloud at a rate of approximately 12%. Most rain events would be included in this figure as such conditions would be associated with strong backscattering in the near range. Two interesting peaks evident are centered around 4 and 10 km. The first likely coincides with the average freezing level. The second indicates the mean cirrus cloud base level. The data set is for the first detected cloud base. High cirrus as a cloud base is infrequent, partially due to the fact that in any multiple cloud situation, lower clouds will get counted first. The more advanced processing gives the height of multiple cloud layers, when seen from the surface. Cloud climatology statistics such as this will be very important for studying cloud cover changes over periods of decades. The MPL cloud height data set are used by studies involving ARM data such as the CAGEX experiment by Charlock (1996).

Further cloud application of the MPL data is to retrieve the optical thickness and extinction cross section of both thin cirrus and aerosol and is being operationally tested. A well known cirrus analysis uses the height profile of the signal and correlation of the integrated cloud return signal with the thermal or visible background radiation at the surface (Platt, 1979). Alternatively, the optical thickness and extinction cross section profile may be estimated from the lidar measurement alone. For optical thickness less than approximately one, the attenuation of the molecular and aerosol return signal from beyond the cloud top can give the cloud optical thickness. Due to the small field-of-view (FOV) of the MPL system (100μrad), a multiple scattering correction is not required as for most lidar systems with much larger FOV.

The aerosol optical thickness and extinction profile may be similarly analyzed from the lidar data. The aerosol retrieval is described in detail by a companion paper in this volume (Campbell et al, 1999).

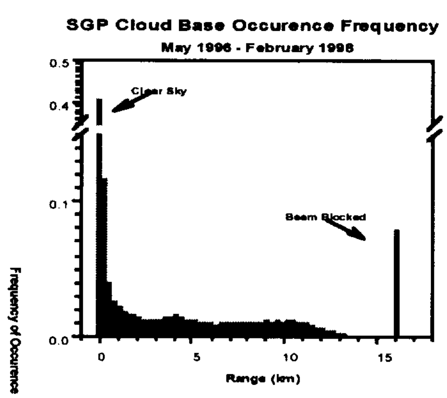

Figure 1. Cloud base height observational frequencies at the ARM SGP site calculated by the MCBH algorithm between May 1996 - February 1998.

3. SUMMARY

The operation of full time MPL instuments at the ARM program sites has introduced a unique and revolutionary measurement set from lidar monitoring of the atmosphere. A dataset spanning almost six years at the ARM central site in Oklahoma has been created and is available. The MPL dataset is now enhanced from instruments installed in the tropical Pacific and arctic region Standard processing provide cloud top and thickness results up to the limit of signal attenuation. Quantitative data analysis procedures to provide vertically resolved measurements of cirrus and aerosol extinction cross sections are in operational testing. Further improvements of the capabilities of instruments and analysis algoriths are planned.

4. REFERENCES

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