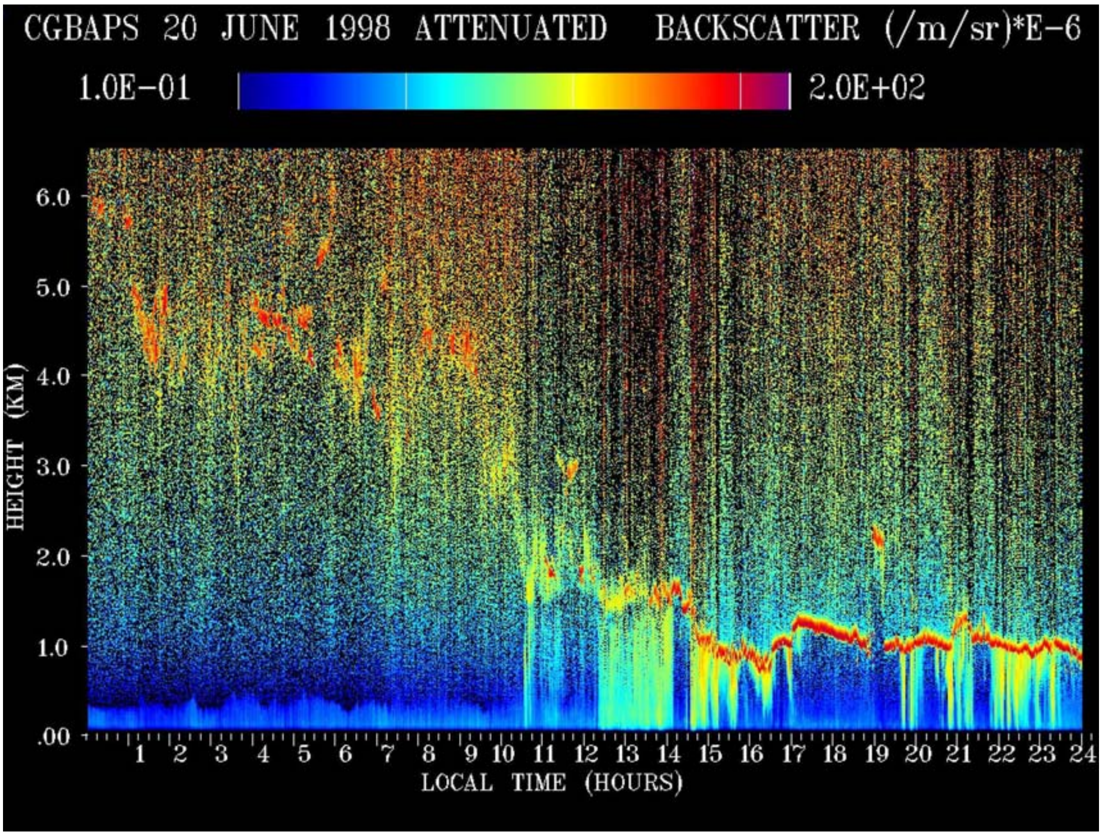
The Cape Grim MiniLidar data set 1998 – 2000: Data coverage, file format and reading software.

Stuart A. Young

CSIRO Marine and Atmospheric Research Paper No. 007

May 2006



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The Cape Grim MiniLidar data set 1998 – 2000: Data coverage, file format and reading software.

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ABSTRACT

A lidar (named the MiniLidar on account of the small laser transmitter) was operated at Cape Grim Baseline Air Pollution Station during the period from June 1998 to October 2000. Although shortcomings in the selection of the components of the original system led to a steady decline in the quality of the data, there is a large quantity of useful data on the location and variability of clouds and boundary-layer aerosols. This work describes the temporal coverage of the measurements and the structure of the data files. A description of the equations required to convert the recorded signals to profiles of attenuated backscatter coefficient is supported by examples of FORTRAN subroutines that have been used at Aspendale to unpack, read and scale the data. Explanation of various anomalies in the data is also provided.

1. INTRODUCTION

The development of the MiniLidar, the difficulties faced, and the consequences of the selection of the components on data quality and system lifetime is summarised in Young (2001) and will not be repeated here. Also covered in that document are the initial deployment of an early version of the system at Cape Grim during SOCEX (Southern Ocean Cloud Experiment) 2 in 1995 and the eventual deployment of the MiniLidar as an autonomous, remotely controllable system making full-time observations at Cape Grim in June 1998. Proposals for a new scientific program based on an upgraded system were also presented.

The results of the analyses of MiniLidar data recorded during SOCEX2 are presented in Pickett (1999), Pickett *et al.* (1996b) and Young *et al*. (1996). Comparisons of the results of the cloud analyses during SOCEX1 and SOCEX2 have been published in Pickett (1999) and Pickett *et al*. (1996b). A study performed at Cape Grim in August 1998 involving a Liquid Water Radiometer, satellite GPS measurements and the MiniLidar was presented in Boers *et al.* (2001).

The aim of this paper is to present the coverage and completeness of the data and to describe the equations and processes needed to convert the recorded data into atmospheric profiles of interest to the user. The equations that relate the lidar profile data to the atmospheric attenuated backscatter and the various equipment setting parameters stored in the data headers for each record are described in Section 4. The structure of the files is described in Section 5 and the procedure for reading, unpacking, and scaling the data is described in Section 6 with reference to FORTRAN subroutines provided as examples in the Appendices.

A document on the interpretation of the MiniLidar data in terms of various atmospheric quantities is also in preparation (Young, in preparation).

2. COVERAGE AND COMPLETENESS OF THE DATA SET

The MiniLidar was operational at CGBAPS for two periods during 1998 to 2000. Data recording was interrupted by the return to Aspendale for three months (March - May 1999) for refurbishment. Table 1 lists the data availability for each month of operation. Data were recorded on 671 days in 25 months during the period. The lidar data volume is just under 3 Giga-bytes.

Table.1. Summary of Mini-Lidar data recorded at CGBAPS during 1998 – 2000.

Year	Month	Start Day	End Day	Total days	Lidar File Size	Met File Size
1998	6	3	30	27	113.00	5.12
	7	1	31	31	85.30	5.05
	8	1	30	11	29.20	2.52
	9	1	30	30	134.00	5.32
	10	1	31	31	147.00	4.46
	11	1	30	30	125.00	4.46
	12	1	31	31	135.00	4.98
1999	1	1	30	30	118.00	4.98
	2	1	25	10	5.97	1.71
	6	10	30	21	91.50	3.95
	7	1	31	31	144.00	5.32
	8	1	31	31	147.00	5.32
	9	1	30	30	140.00	5.15
	10	1	31	29	144.00	5.31
	11	1	30	30	138.00	5.14
	12	1	31	26	60.50	3.60
2000	1	1	31	31	94.10	5.27
	2	1	29	26	90.00	4.96
	3	1	31	31	221.00	5.30
	4	1	30	30	139.00	5.14
	5	1	31	31	165.00	5.32
	6	1	30	30	150.00	4.98
	7	1	31	26	118.00	4.29
	8	1	31	31	162.00	5.46
	9	1	24	6	33.40	3.95
Totals	**25 months**			**671 days**	**2929.97 MB**	**117.06 MB**

3. THE MINILIDAR SYSTEM

The details are of the system as it operated during SOCEX 2 are presented in Pickett (1999) and Pickett *et al.*, (1996b), and a brief description of the changes made for the upgraded system deployed during 1998 to 2000 was presented in Boers *et al.* (2001). Therefore description here of system details will be limited to that required for understanding the various system parameters used in the analysis presented in Section 4.

The MiniLidar transmitter was a Kigre Model MK-480, pulsed Nd:YAG laser head driven by a custom-built power supply. Maximum output energy at 1064 nm, when new, was about 15 mJ with a minimum firing interval of about 3 seconds. The laser output energy was measured using a calibrated energy module that was illuminated by some of the laser energy scattered by the output optics. The signal backscattered from the atmosphere was collected in a 40-cm diameter telescope with a detector module placed at the prime focus. The YAG-444 Silicon PIN photodiode detector was followed by a preamplifier whose variable gain was adjusted by the control software via the PC. The output signal from the preamplifier was digitized by a CompuScope Model 220, 2-channel, 8-bit, 40-Msps digitizer.

The digitizer's sensitivity and sample interval and the transfer of the digitized record were also under software command. The variable gains and digitizer sensitivities were required to permit the scaling of the atmospheric backscatter signal, which could vary over many orders of magnitude, into the 256 levels of the 8-bit digitizer. The amplifier and digitizer settings were saved in the file header.

Typically, two simultaneous profiles, one at low gain and one at high gain, were recorded every minute, but more profiles were often recorded while the control software adjusted the gains in order to digitize the signals optimally. The two-channel recording mode was necessary because the dynamic range of the lidar signal was usually many orders of magnitude while the 8-bit digitizer, which lacked a signal level offset adjustment, was limited to only about 127 recording levels or two orders of magnitude. Because the digitizer tolerated only a small degree of overdriving at the input, the high-gain signal had to be limited in magnitude. Initial tests with a logarithmic amplifier were unsatisfactory with the high noise levels involved and more satisfactory results were obtained by simply limiting the signal amplitude with a diode. Most of the MiniLidar data recorded at Cape Grim used this recording mode. The high- and low-gain signals can be merged when detailed analysis of both weak aerosol and stronger cloud features is required.

4. RELATIONSHIP OF RECORDED LIDAR SIGNALS TO ATMOSPHERIC PARAMETERS

The backscattered signal power *P(r)* at the detector, received from a range *r* from the lidar, for an atmosphere containing molecules and particles (aerosols and clouds) can be written:

$$P(r) = \{\eta_O EAc/2\}[\beta_M(r) + \beta_P(r)]T_M^2(0,r)T_P^2(0,r)/r^2 + P_0\,, \tag{1}$$

where

η_O is the optical efficiency of the lidar system,

E is the laser energy in the transmitted pulse,

A is the effective area of the telescope receiver (0.13 m^2 for the MiniLidar)

c is the velocity of light, and

P_0 is the offset power resulting from background sky light.

$\beta_M(r)$ is the backscatter coefficient for molecules at range *r*,

$\beta_P(r)$ is the backscatter coefficient for particles at range *r*,

$T_M^2(0,r)$ is the two-way molecular transmittance from the lidar to range *r*, and

$T_P^2(0,r)$ is the two-way particulate transmittance from the lidar to range *r*.

The signal is then detected, amplified, scaled and digitized before being written to disk along with various setting parameters. The digitized signal can be related to various instrumental settings:

$$D(r) = [A_1 R_L S_D P(r) + A_0]2^{NBITS}/VFS + D_O \tag{2}$$

when a linear amplifier is used. If we express the attenuated backscatter as

$$\beta'(r) = [\beta_M(r) + \beta_P(r)]T_M^2(0,r)T_P^2(0,r)\,, \tag{3}$$

then we can derive an expression for this atmospheric quantity in terms of the measured signal and the instrumental settings:

$$\beta'(r) = [C_0 - D(r)]r^2 / C_1\,. \tag{4}$$

We can now write the offset term as

$$C_0 = D_0 + (2^{NBITS} / VFS)\left[A_0 + A_1 R_L S_D P_0\right], \tag{5}$$

and the scale factor as

$$C_1 = (2^{NBITS} / VFS)\left[A_1 R_L S_D \left(E_0 + E_1 PEM\right)\eta_O A(c/2)\right]. \tag{6}$$

The various equipment parameters appearing in these equations are defined:

A_0	is the linear amplifier offset,
A_1	is the linear amplifier gain,
D_0	is the digitizer offset (nominally 127 for the MiniLidar),
E_0	is the energy monitor offset,
E_1	is the energy monitor gain,
PEM	is the digital output from the laser pulse energy monitor,
R_L	is the detector load resistor (50 ohms),
S_D	is the sensitivity of the detector (0.243 A/W for the MiniLidar),
$NBITS$	is the amplitude resolution of the digitizer (8 for the MiniLidar).
VFS	is the full-scale voltage for the digitizer.

Note that the digitizer used in the MiniLidar nominally sets an input of zero volts to the digital level 127 (although other values can be used). Values of –VFS and +VFS are assigned levels of 0 and 256 respectively. Because of variations in the background sky brightness, and amplifier gain and offset with temperature, the signal offset C_0 is usually determined from regions of the digitized signal where contributions from atmospheric backscattering features are negligible compared to the noise (e.g. the last 50 or 100 points in the record).

The lidar range *r* is calculated from the digitizer array index *j* using the equation

$$r = \left(c/2\right)[T_0 + \left(j-1\right)T_1]\,, \tag{7}$$

where T_0 is the digitizer delay time and T_1 the digitizer sample interval.

The altitude above mean sea level of any range *r* is calculated by adding the lidar altitude (stored in the lidar header) to the range. For operations at Cape Grim this was 95 m.

5. STRUCTURE OF THE MINILIDAR DATA RECORDS

The MiniLidar was controlled via an IBM PC clone running MS-DOS and communicating with the network via PCNFS software. The lidar control and data acquisition program was written in Lahey F77L v5.0, 16-bit FORTRAN. As a result, the data byte structure is "little-endian". The data file type is Lahey FORTRAN binary, direct-access type with a header record.

All the lidar data files recorded since 1987 by the CSIRO Aspendale lidar team follow the same naming convention and this was also used for the MiniLidar data. The lidar data were recorded as pairs of files with the names of the form FILEnnn.INX and FILEnnn.LID. For the MiniLidar, nnn is a three-digit number representing the day number in the year. For various reasons, the "shot" or profile number in some of the lidar files is different from the record number in the lidar FILEnnn.LID file. Therefore all files have a companion index file (FILEnnn.INX) that gives the record number corresponding to a particular shot number; the latter is the variable stored in the lidar data header. However, for most, if not all, of the MiniLidar data, this precaution is unnecessary.

On each laser firing, instrument setting and digitized backscatter profile data were recorded as a 50-word lidar header containing the settings followed by 1024 bytes of 8-bit profile data packed two to a 16-bit word with the first sample in the upper byte of the first word. Usually two channels of data were recorded on each laser firing with a low-gain signal recorded on even record numbers and a high-gain signal recorded on the odd numbers with record numbers beginning at unity. The reason for this is discussed in Section 3 above.

Table 2: MiniLidar data header contents

Index	Symbol	Description	Index	Symbol	Description
1	34	Laser & digitizer code	26	0	Range gate delay (m)
2		Error code (0 = ok)	27	3	Optical path number
3		Seconds (ss)	28	0	Amplif. attenuation (dB)
4		Minutes (mm)	29	64	Linear Amplifier (0=out)
5		Hours (hh)	30	0	Log. Amplifier (0=out)
6		Day (DD)	31	12	Receiver FOV (mrad)
7		Month (MM)	32	0	Coarse ND Filter D*1000
8		Year (YY = 98, 99, or 00)	33	$100*A_1$	Lin. Amp. Gain * 100
9	2	Operator (2=SAY)	34	$1000*A_0$	Lin. Amp. Offset * 1000
10		centi-seconds	35	20597	Log. Amp. Gain*1000
11	0	Scan number	36	17211	Log. Amp. Offset*1000
12		Shot number	37	$1E6*E_1$	Energy Mon. Gain*1E6
13	T_1	Sample interval (ns)	38	E_0	Energy Mon. Offset
14		Input range (mV)	39	$1000*\eta_O$	System Opt. Eff.*1000
15	D_O	Digitizer Offset levels	40		File Number
16	$10*T_1$	Trigger delay (ns*10)	41	0	Azimuth Angle (0.1 deg)
17	0	PMT EHT (V)	42	900	Elevation Angle (0.1deg)
18	4	Detector number	43	*PEM*	Energy Monitor output
19	1	Number of shots averaged	44	1	Wavelength number
20		Coupling (0=DC,1=AC)	45	2	Number of channels

21	0	Fine ND Filter D*1000	46	0	Laser Temp. (0.1 deg. C)
22	3=none	Polarizer / NBF/ NDF index	47		Sky background * 10
23	60	Recording interval	48	1024	Samples per channel
24		Channel number (1 or 2)	49	9999	IR Radiance (0.1 mV)
25	20000	Low-pass filter BW (kHz)	50	95	Lidar altitude AMSL (m)

The contents of the 50-word header are listed in Table 2 along with the symbol of the variable used in Section 4 where relevant, or the default value if the parameter is constant (or unused) for the MiniLidar data set.

Note that the digitizer offset (items 15 and 47) is estimated during recording from the average value of the digitized signal over the last 100 sample points on the assumption that there will be only noise in this region. Any atmospheric signal in this region will cause the estimate to be in error.

The index files are binary files with a record length of 2 bytes. The first byte is an identifying header with a hexadecimal value of F6. Subsequent records give the shot number stored at a given record in the LID file. The first part of an index file is shown in Figure 1. The left column gives the hexadecimal address while the remaining sixteen columns in a row contain the byte-reversed contents of eight records per line. The output was produced on a personal computer running Microsoft Windows XP.

```
00000000  F6 00 01 00  02 00 03 00  04 00 05 00  06 00 07 00
00000010  08 00 09 00  0A 00 0B 00  0C 00 0D 00  0E 00 0F 00
00000020  10 00 11 00  12 00 13 00  14 00 15 00  16 00 17 00
00000030  18 00 19 00  1A 00 1B 00  1C 00 1D 00  1E 00 1F 00
00000040  20 00 21 00  22 00 23 00  24 00 25 00  26 00 27 00
00000050  28 00 29 00  2A 00 2B 00  2C 00 2D 00  2E 00 2F 00
00000060  30 00 31 00  32 00 33 00  34 00 35 00  36 00 37 00
00000070  38 00 39 00  3A 00 3B 00  3C 00 3D 00  3E 00 3F 00
00000080  40 00 41 00  42 00 43 00  44 00 45 00  46 00 47 00
00000090  48 00 49 00  4A 00 4B 00  4C 00 4D 00  4E 00 4F 00
000000A0  50 00 51 00  52 00 53 00  54 00 55 00  56 00 57 00
000000B0  58 00 59 00  5A 00 5B 00  5C 00 5D 00  5E 00 5F 00
000000C0  60 00 61 00  62 00 63 00  64 00 65 00  66 00 67 00
000000D0  68 00 69 00  6A 00 6B 00  6C 00 6D 00  6E 00 6F 00
000000E0  70 00 71 00  72 00 73 00  74 00 75 00  76 00 77 00
000000F0  78 00 79 00  7A 00 7B 00  7C 00 7D 00  7E 00 7F 00
00000100  80 00 81 00  82 00 83 00  84 00 85 00  86 00 87 00
00000110  88 00 89 00  8A 00 8B 00  8C 00 8D 00  8E 00 8F 00
00000120  90 00 91 00  92 00 93 00  94 00 95 00  96 00 97 00
00000130  98 00 99 00  9A 00 9B 00  9C 00 9D 00  9E 00 9F 00
00000140  A0 00 A1 00  A2 00 A3 00  A4 00 A5 00  A6 00 A7 00
```

Figure 1: Structure of an index (INX) file as viewed on a PC running MS Windows XP.

The data records also have a Lahey FORTRAN direct file header. The first byte is an identifier (F7). The next two bytes contain the byte-reversed record length. In the example shown in Figure 2, the record length can be read as hexadecimal 0464 which equates to 1124 when expressed as a decimal number. The rest of the first record is empty in the MiniLidar data and the actual data begin at the second word beginning at hexadecimal address 0464. The first entry is hexadecimal 22, or 34 in decimal, which is the identifier for the MiniLidar made up of an index of 4 for the particular laser and 3 for the CompuScope digitizer card. The first fifty two-byte words constitute the lidar header and contain the settings listed in Table 2. The 1024 profile data records are then packed into the remaining 512 two-byte words. The 50-word settings header block for the next shot follows immediately and is itself followed by the profile data. The data structure for the lidar data (LID) files is shown in Figure 3.

A profile of the raw digitizer signal from a strong cloud bank over Cape Grim on the 20th of June 1998 is shown in Figure 4. Note that negatively-biased detector causes increases in the backscattered signal power to be recorded as decreases in the digitized signal from the zero-signal level of about 185 units in the example shown. The corresponding profile of attenuated backscatter is shown in Figure 5. The increase in noise with range from the lidar results from the scaling of the digitizer signal by the square of the range as shown in Equation 4.

```
00000000  F7 64 04 00  00 00 00 00  00 00 00 00  00 00 00 00
00000010  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
00000020  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
.
.
.
00000450  00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
00000460  00 00 00 00  22 00 04 00  37 00 09 00  00 00 1E 00
00000470  09 00 00 00  02 00 00 00  00 00 01 00  32 00 E8 03
00000480  93 00 01 00  00 00 04 00  01 00 00 00  00 00 03 00
00000490  3C 00 01 00  20 4E 00 00  1E 00 00 00  40 00 00 00
000004A0  0C 00 00 00  FC 01 00 00  75 50 3B 43  7A 3F DB FF
000004B0  01 00 12 01  00 00 84 03  01 00 01 00  02 00 00 00
000004C0  BE 05 00 04  0F 27 5F 00  93 93 28 94  18 0C 4E 34
000004D0  6E 61 7F 79  85 83 89 88  8D 8B 8C 8D  90 8E 90 90
```

Figure 2: Structure of part of a lidar data (LID) file as viewed on a PC running MS Windows XP. See text for details.

Record number	**Contents**	**Length in bytes**	**Start byte in file**
1			
(Lahey)	Lahey File identifier	1	1
	Record length	2	2
	Filler zeros	1121	4
2			
DATA	Record Header	100	1025
(1st profile)	Profile data for shot	1024	1125
3			
(2nd profile)	Profile data for shot	1024	2249
DATA	Record Header	100	2349

Figure 3: Overall structure of a lidar data file.

6. DESCRIPTION OF THE USE OF EXAMPLE FORTRAN ROUTINES TO UNPACK, READ AND SCALE THE LIDAR DATA

Now we consider the process required to produce profiles of attenuated backscatter from the MiniLidar files. Essentially, this involves the following steps: selection of the required file, selection of the required record, opening the file, reading the record, unpacking the data into header and profile arrays, then scaling the data. To assist the reader in this process, examples of several FORTRAN subroutines written by the author, and based on those used in the past for the analysis of data from various CSIRO lidars including the MiniLidar, are presented in the appendices. They are examples of code that could also be used, if it is desired to do so, to convert all the existing, packed binary data to another format.

The routines were originally written over the period 1987 – 2000 for compilation with the Lahey 16-bit F77L and 32-bit F77L EM/32 compilers. These Lahey compilers contain many FORTRAN 90 and 95 extensions. The routines have been converted here to more modern FORTRAN 90 / 95 code and tested successfully on three different modern FORTRAN compilers. The example code consists of a main program that calls some subroutines to demonstrate the way in which the data can be read, unpacked, scaled and saved.

The first step is to select the desired file. This is obtained by appending the 3-digit day number of the year to the prefix "FILE" and then appending the extension ".LID". For data recorded on 9th August 1999, the file number is then 221 and the file name "FILE221.LID". Confusion with files from similar day numbers in other years is avoided by using the appropriate directory structure, e.g. " …\cgbaps\lidar\1999\aug\". One way of reading the file is shown in the example PROGRAM READMINI in Appendix 1. Note that some lines that are single lines in the code appear wrapped in the appendices here.

The record number for a particular shot number can be determined from the index file. As shot numbers in the MiniLidar records under consideration are aligned with the record numbers, the use of the index (INX) files could be bypassed and the shot number could be used directly as the record number. Note how the first record is skipped as the files have a Lahey F77L direct file header that was used to determine record and file length. (These features are not used in the new code as they are not portable to all compilers.)

Once the file is opened and positioned, the required record is read. As the 16-bit header data are packed, two words into every 32-bit word, they must be unpacked as in SUBROUTINE UNPACKH. Then the profile data are read. These are packed four 8-bit bytes to one 32-bit word. They are unpacked as in BYTESEP32. Finally the data are scaled by the header data and converted into profiles of attenuated backscatter. A suggested method for achieving this is shown in SUBROUTINE SCALE_MINI in Appendix 4. The code follows the equations in Section 4 above to help the reader follow the process.

Note that the code examples provided here are written assuming the use of a modern 32-bit compiler and assume that data are read in as 32-bit words. It is possible, however, to read the data as 16-bit words, but then changes would need to be made to the software. The 16-bit header data would not need to be unpacked and there would only be two 8-bit data words to one 16-bit word. For guidance on what would be required, a fragment of the original 16-bit F77L code that was used to write the data files is provided in Appendix 5.

Finally, an example of the output of the PROGRAM READMINI is presented in Appendix 6. The example is for shot 19 of FILE 274 recorded in September 2000. (The same record is plotted in Figure 6 and the file structure is shown in Figure 2.) The screen dump begins with the entry of the data file directory and file (day) number. The file name is then printed to confirm that the details have been entered correctly. After the record number is entered the contents of the 50-word header block are printed. The time and date can be read from the first line as 00:11:57.00 and 30/09/2000. The next block contains the unpacked, raw digitizer counts, printed twenty to a line. Finally the scaled, attenuated backscatter array is printed with ten entries per line.

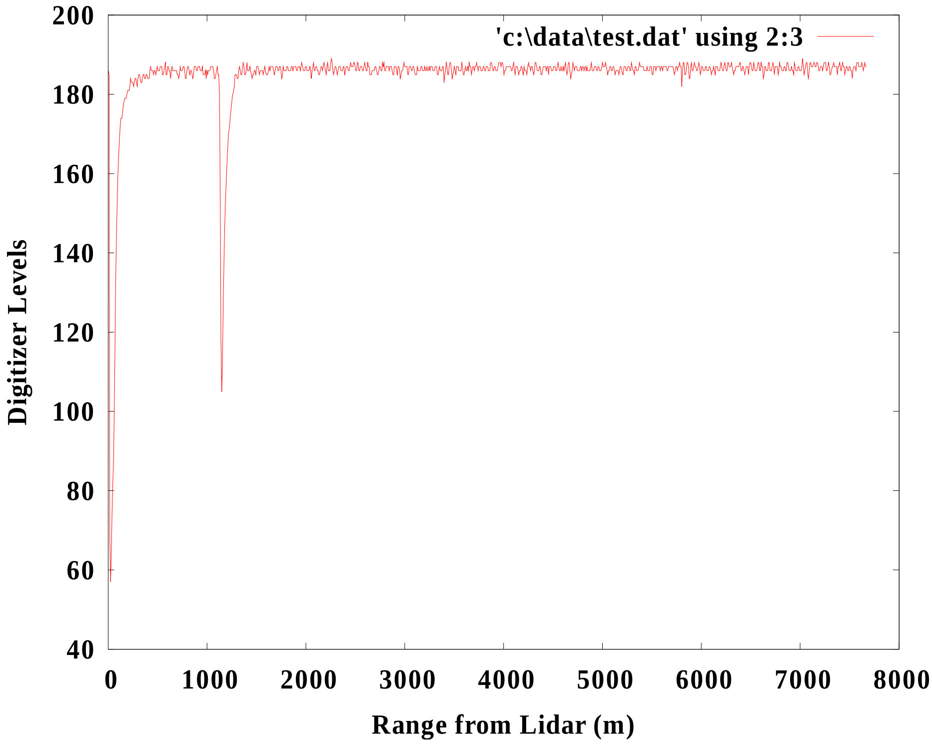

Figure 4: Raw digitizer signal from a cloud at 1150 m above the lidar (1245m altitude). A zero offset of approximately 185 levels is used to accommodate the negatively-going output signal from the detector.

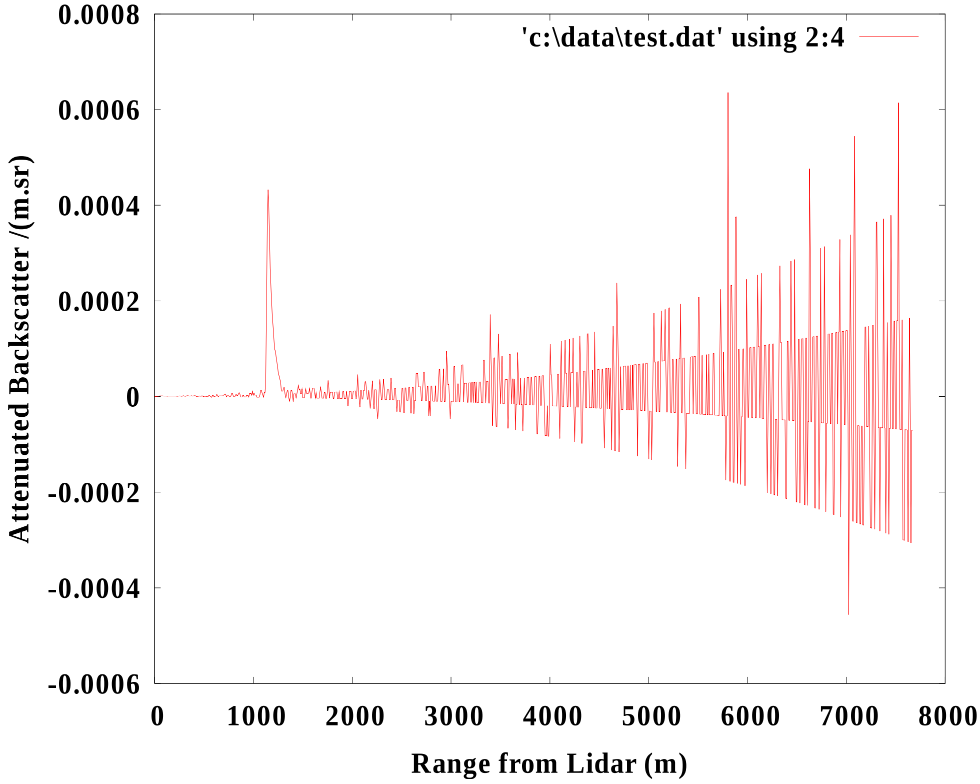

Figure 5: Attenuated backscatter profile from the cloud in Figure 4. Note that the noise in Figure 4 is scaled by the square of the range according to Equation 4.

7. CAVEATS ON THE USE OF THE DATA

It needs to be stressed here that the performance of MiniLidar was severely compromised by the early choices of several of the major components and these limit the degree to which accurate, scaled, attenuated backscatter data can be produced. The problem results mainly from variabilities in recording of the laser output energy through the parameters E_0 and E_1. Smaller variations result from the variation in the optical path transmittance η_O (which includes the cleanliness of the window in the laboratory roof) and in the temperature dependence of the sensitivity of the detector (S_D in Equation 4).

Multiple pulsing of the laser

The laser used in the MiniLidar had a rather limited life in terms of the number of pulses it could produce. During the lifetime of the laser, the output energy dropped steadily from a value (around 15 mJ) that was already marginal in producing an adequate signal and the laser output had to be increased by increasing the energy to the flashlamp, although the laser output energy finally dropped to levels that were too low to be useful. Unfortunately, the increased flashlamp energy increased the tendency of the laser to produce multiple pulses. This causes two problems. First, the laser energy monitor samples the total energy transmitted during a time interval of approximately 50 microseconds. If a second or third laser pulse occurs within this time frame the recorded energy can be two or three times the correct value and the scaling in equation 4 will be in error. Also, during the deployment of the system, the coupling of the energy to the energy monitor changed so the coefficients E_0 and E_1 varied. Another concern was that the energy of the laser was so low and so variable that these coefficients could not be determined precisely during the calibration of the laser energy monitor.

The second problem that results from multiple pulses is the interpretation of the signal. The multiple pulsing of the laser effectively causes the atmospheric backscatter signal profile to be convolved with a series of delta functions. While interpretation is not impossible so long as the second and subsequent pulses occur after the arrival of the highest cloud signal, automatic analysis of the data is extremely difficult, if not impossible, when this is not the case. A profile showing the effects of multiple pulsing is presented in Figure 6. A cloud layer is apparent at a range of about 900 m. A height versus time plot of the logarithm of the range-squared power (proportional to the attenuated backscatter) is shown in Figure 7.

Mis-triggering of the digitizer

Occasionally, perhaps four or five times per day, (no accurate statistics have been accumulated) the digitizer data are apparently shifted to the left and the signal from the lowest region of the atmosphere is missing. The error occurred so infrequently that the cause was never identified. It is assumed to be either a mis-triggering or a fault in the memory management of the digitizer.

Amplifier gain changes

As the signal from the atmosphere varies considerably, the recording software adjusts the gain of the amplifier and sensitivity of the digitizer so as to produce an optimal recording of the signal. The recording of a new profile begins every minute and it may take up to five adjustments to find the correct settings, especially when the atmosphere is changing rapidly as happens when there is broken cloud overhead. It can happen that the first few profiles recorded every minute may be recorded at too high a gain setting causing a nonlinear recovery of the digitizer. For this reason, the shot pair recorded last in every minute is likely to be of the highest quality. The low-gain channel recorded on channel 1, and assigned odd-numbered shots, is the channel whose sensitivity is adjusted and is, therefore, of higher quality than the high-gain channel 2 where only the amplifier gain is adjusted.

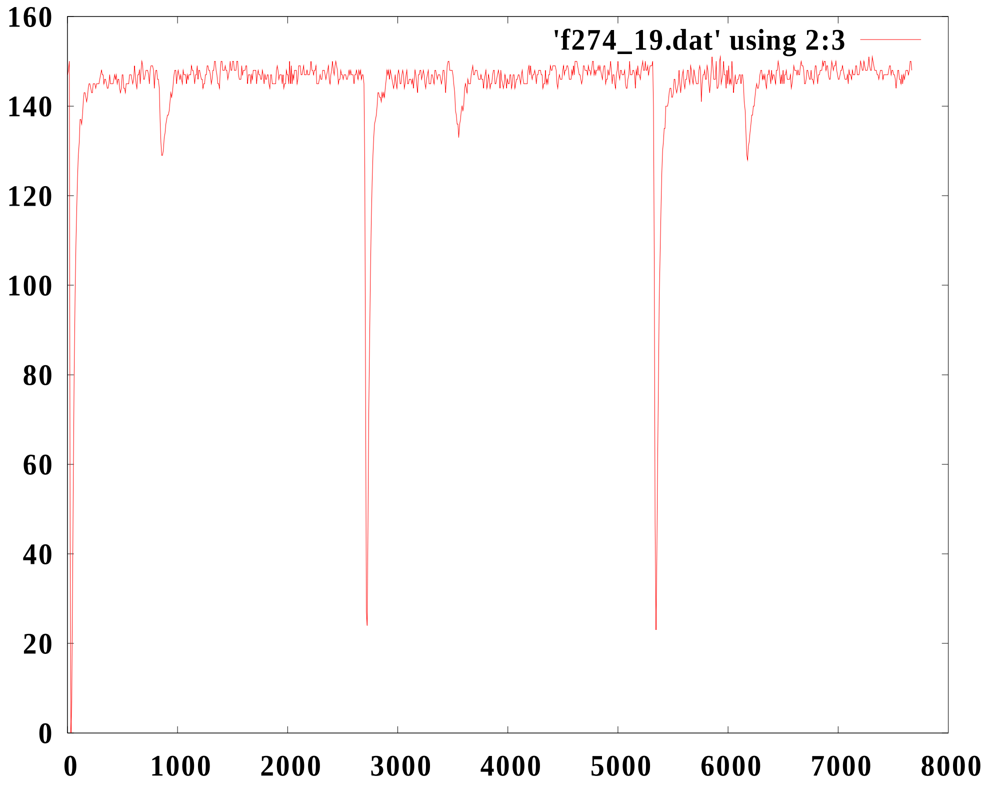

Figure 6: Digitizer output showing the effects of multiple pulsing of the laser.

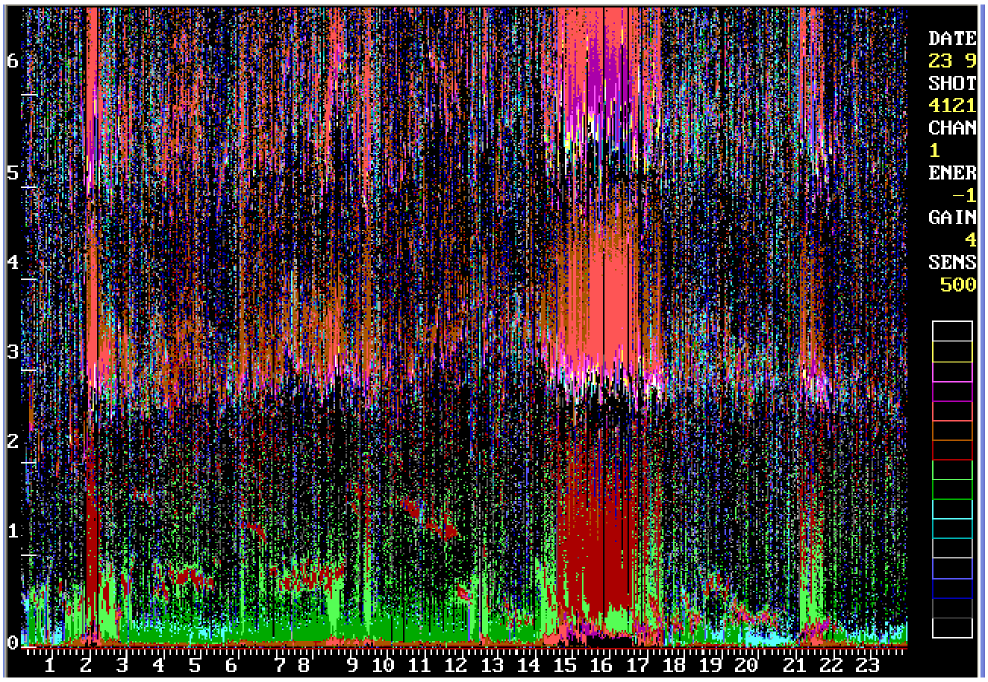

Figure 7: Attenuated backscatter data for the 23rd September 2000, during the penultimate week of observations at CGBAPS, plotted on height versus time axes. The colour scale at the right indicates the relative magnitude of the variable. The low laser energy has required an assumed calibration of the data and has resulted in a reduced sensitivity. Multiple pulsing of the laser is indicated by spurious returns about 3 km and 5 km range.

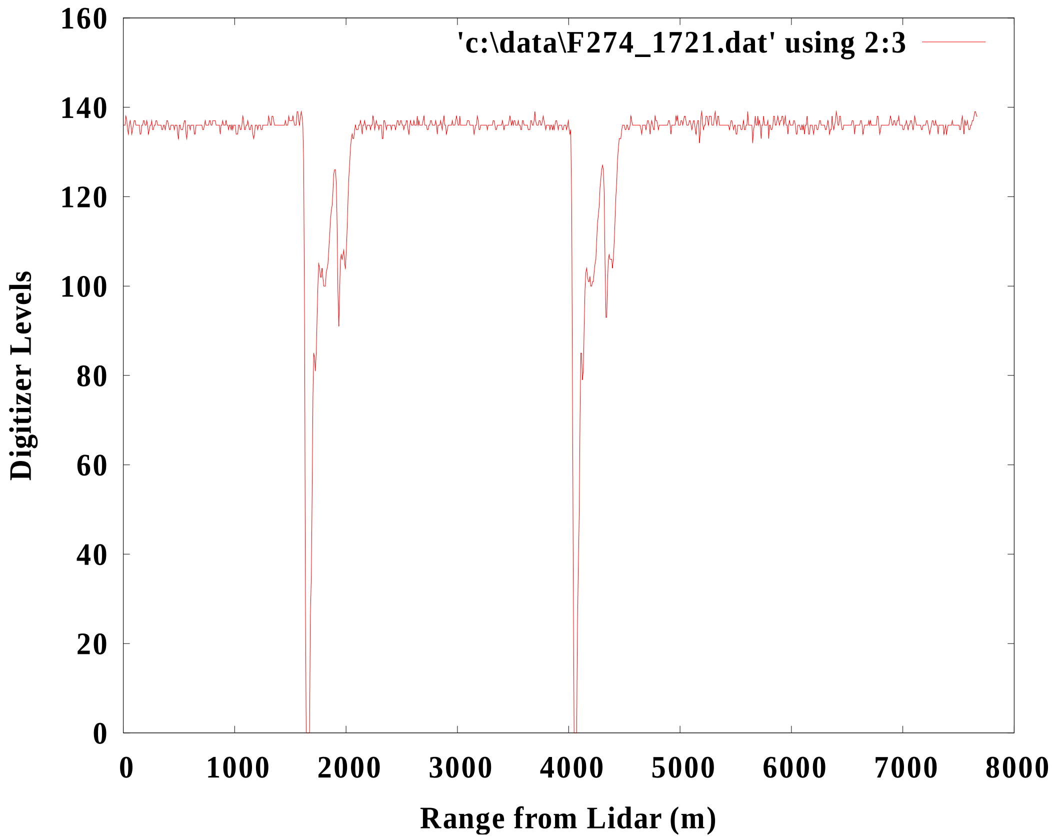

Figure 8: Digitizer output showing the effects of multiple pulsing of the laser and mis-triggering of the digitizer resulting in range errors. This error occurs very rarely

Note on the Use of the MiniLidar data

The MiniLidar Data are to be archived by the Bureau of Meterology and can be obtained by contacting the Officer-in-Charge of the Cape Grim Baseline Air Pollution Station (cgbaps@bom.gov.au).

As a courtesy to the scientists who worked on the development of the MiniLidar and the control and analysis software, and who were involved in the operation of the system and in the recording and processing of the considerable volume of data, users of the data are requested to acknowledge the efforts of the people who performed by bulk of the work, namely Stuart A. Young and Graeme R. Patterson, in any reports or scientific presentations that make use of the data.

Any users who consider using the data in scientific publications are requested to contact the author to investigate the possibility of collaboration.

Acknowledgments

The author gratefully acknowledges the assistance of some former members of CSIRO Atmospheric Research. Graeme Patterson designed some of the improved electronics and wrote the data acquisition software to drive the digitizer card and energy monitor. Reinout Boers modified some software, written by Denis O’Brien following discussions with the author, to enable remote control of the lidar system over the internet. The staff of the Electronics Development Laboratory at Aspendale, led by John Bennett, assembled, tested and calibrated various electronic circuits employed in the system.

Without the friendly, willing and extremely capable support of staff of the Cape Grim Baseline Air Pollution Station, the deployment of the system at Cape Grim and its control from Aspendale would have been impossible. The collaboration of Stuart Baly, Alan Gough, Laurie Porter and Brian Weymouth was particularly valuable.

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References

Boers, R., Young, S. A., O'Brien, D. M., Bennett., J. W., Tregoning, P., and Hendy, M. (2001). “Microwave, GPS and Lidar observations at Cape Grim”. In: Baseline Atmospheric Program Australia. 1997-98 ed. N. W. Tindale, N. Derek, and R. J. Francey (editors). Melbourne: Bureau of Meteorology and CSIRO Atmospheric Research. pp. 105-108.

Pickett, M. C., (1999) “Lidar and Infrared Radiometer Studies of Stratocumulus Clouds”, PhD thesis, Optical Technology Research Laboratory, School of Communications and Informatics, Victoria University.

Pickett, M. C., Young, S. A., Boers, R., and Platt, C. M. R. (1996a). “Lidar observations of boundary layer clouds during the Southern Ocean Cloud Experiment.” In: Baseline Atmospheric Program Australia. 1994-95 ed. R. J. Francey, A. L. Dick, and N. Derek (editors). [Melbourne]: Bureau of Meteorology and CSIRO Division of Atmospheric Research. p. 10-21.

Pickett, M. C., Young, S. A., and Platt, C. M. R. (1996b). “Lidar and infrared radiometer measurements of clouds during SOCEX II.” In: Baseline Atmospheric Program Australia. 1994-95 ed. R. J. Francey, A. L. Dick, and N. Derek (editors). [Melbourne]: Bureau of Meteorology and CSIRO Division of Atmospheric Research. p. 158-159.

Young, S. A. (2001) “The Minilidar: Where to from here?” CAR Internal Paper Number 22 (submitted). 24-pages.

Young, S. A., Pickett, M. C., Manson, P. J., and Platt, C. M. R. (1996). Lidar and infrared radiometer measurements of clouds during SOCEX I. In: Baseline Atmospheric Program Australia. 1993 ed. R. J. Francey, A. L. Dick, and N. Derek (editors). [Melbourne]: Department of the Environment, Sport and Territories, Bureau of Meteorology in cooperation with CSIRO Division of Atmospheric Research. pp. 104-106.

Young, S. A. (2007) “Interpretation of the MiniLidar data recorded at Cape Grim 1998-2000.” Document in preparation for submission to “Baseline Atmospheric Program Australia 2005-2006”.

Appendix 1: Example of a FORTRAN Program to read Minilidar data.

```
    MODULE Constants_Module
    IMPLICIT NONE
    PUBLIC               ::  ShortInteger, LongInteger
    INTEGER, PARAMETER   ::  ShortInteger=SELECTED_INT_KIND(4)
    INTEGER, PARAMETER   ::  LongInteger =SELECTED_INT_KIND(8)
    END MODULE Constants_Module
!
    PROGRAM ReadMini
!-----------------------------------------------------------------------
!   Modules
!-----------------------------------------------------------------------
    USE Constants_Module
!-----------------------------------------------------------------------
!   Local variables
!-----------------------------------------------------------------------
    IMPLICIT NONE
    INTEGER                                     :: irec    ! record number
    INTEGER                                     :: jrec    ! shifted recnum
    INTEGER (ShortInteger)                      :: fnum    ! file number
    INTEGER                                     :: i,j     ! loop indices
    INTEGER (LongInteger) ,  DIMENSION(25)      :: pset
    INTEGER (LongInteger) ,  DIMENSION(256)     :: pdat
    INTEGER (ShortInteger),  DIMENSION(50)      :: iset
    INTEGER (ShortInteger),  DIMENSION(1024)    :: idat
    REAL                  ,  DIMENSION(1024)    :: rnge    ! range array
    REAL                  ,  DIMENSION(1024)    :: bt2     ! attenuated
                                                           ! backscatter array
    CHARACTER          (LEN=128)                :: path
    CHARACTER          (LEN=11)                 :: filename
    INTEGER                                     :: FileUnit = 1
!-----------------------------------------------------------------------
!   MiniLidar Data specific values
!-----------------------------------------------------------------------
    INTEGER (LongInteger)     :: first = 1
    INTEGER (LongInteger)     :: rlen  = 1124 ! record length of file
    INTEGER (LongInteger)     :: ioff  = 1    ! offset caused by F77L Header
    INTEGER (LongInteger)     :: phdim = 25   ! packed header size
    INTEGER (LongInteger)     :: pddim = 256  ! packed data size in bytes
    INTEGER (LongInteger)     :: np           ! number of points in profile
!-----------------------------------------------------------------------

    WRITE(*,*)' Enter path to file (include trailing "\") '
    READ(*,*)   path
    WRITE(*,*)' Enter File number (Day of Year) (I3) '
    READ(*,*)   fnum

    filename = 'file000.lid'
    WRITE (filename(5:7),200) fnum
200 FORMAT(I3.3)
    WRITE(*,*)'filename= ',TRIM(path)//filename

    OPEN (UNIT=FileUnit,FILE=TRIM(path)//filename,ACCESS='DIRECT',RECL=rlen)


    DO
100     WRITE(*,*)' Enter record (shot) number   '
        READ(*,*) irec
        jrec = ioff + irec
        READ(FileUnit,REC=jrec,ERR=100)(pset(i),i=1,phdim),     &
                                      (pdat(i),i=1,pddim)
        EXIT
    END DO
```

```
    CLOSE (UNIT=FileUnit)

    CALL UNPACKH(iset,pset,first,phdim)         ! unpack header data

    np     = iset(48)

    WRITE(*,*) '       Array  Error    Sec    Min   Hour    Day    Mth
Year   Oper   cSec'
    WRITE(*,*) '        Scan   Shot Samp-t  Input Offset  Delay    EHT
detect  avg-s  avg-t'
    WRITE(*,*) '        NDf  Pol/NB   Rate Channel   LPF R-gate Optical
Atten Linamp Logamp'
    WRITE(*,*) '       Apert   NDc  Lin-gn Lin-of Log-gn Log-of  EM-gn  EM-
of Sys-con  File'
    WRITE(*,*) '         Azi    Elv Energy  Wavel S-type   Temp    Sky
Samples IRrad   Alt'
    WRITE(*,*)

    WRITE(*,10) (iset(i),i=1,50)              ! inspect header data
10  FORMAT(T5,10I7)
    WRITE(*,*)
    READ(*,*)                                 ! pause

    CALL BYTESEP32(idat,pdat,first,pddim)     ! Unpack the profile number

    WRITE (*,20) (idat(j),j=1,np)             ! inspect the raw profile data
20  FORMAT(20I4)
    WRITE(*,*)

    CALL SCALE_MINI(bt2,iset,idat,rnge,np)    ! Scale the profile data

    WRITE (*,30) (bt2(j),j=1,np)              ! inspect the raw profile data
30  FORMAT(10(ES11.3))
    WRITE(*,*)

    OPEN(UNIT=FileUnit,FILE=TRIM(path)//'test.dat',ACCESS='SEQUENTIAL')
    DO j = 1,np
        WRITE(FileUnit,40) j,rnge(j),idat(j),bt2(j)
    END DO
    CLOSE (UNIT=FileUnit)
40  FORMAT(I5,F10.2,I5,ES12.4)

    STOP
    END PROGRAM ReadMini
```

Appendix 2: Example of a FORTRAN Subroutine to unpack the header data

```
    SUBROUTINE UNPACKH(iset,pset,first,last)
!-----------------------------------------------------------------------
!
!   UNPACKH splits the header data in PSET into two 16-bit words in ISET
!
!-----------------------------------------------------------------------
    USE Constants_Module
    IMPLICIT NONE
!-----------------------------------------------------------------------
!   Dummy Arguments
!-----------------------------------------------------------------------
    INTEGER (LongInteger),                 INTENT(IN)  :: first
    INTEGER (LongInteger),                 INTENT(IN)  :: last
    INTEGER (LongInteger),   DIMENSION(*), INTENT(IN)  :: pset ! packed
input array
    INTEGER (ShortInteger),  DIMENSION(*), INTENT(OUT) :: iset ! unpacked
array
!-----------------------------------------------------------------------
!   Local Variables
!-----------------------------------------------------------------------
    INTEGER (LongInteger)          :: word ! unpacked word
    INTEGER                        :: i,j
!-----------------------------------------------------------------------

    j = 1
    DO i = first,last
        word  = IAND(pset(i),65535)
        iset(j)= word
        word  = ISHFT(pset(I),-16)
        word  = IAND(word,65535)
        iset(j+1) = word
        j = j + 2
    END DO

    RETURN
    END SUBROUTINE UNPACKH
```

Appendix 3: Example of a FORTRAN Subroutine unpack the profile data

```
    SUBROUTINE BYTESEP32(idat,pdat,first,last)
!-----------------------------------------------------------------------
!
!   BYTESEP32 splits the packed in data in PDAT into four 8-bit words in
!   IDAT
!
!-----------------------------------------------------------------------
!   Dummy Arguments
!-----------------------------------------------------------------------
    IMPLICIT NONE
    INTEGER,    PARAMETER   ::  ShortInt=SELECTED_INT_KIND(4)
    INTEGER,    PARAMETER   ::  LongInt =SELECTED_INT_KIND(8)
    INTEGER (LongInt),                  INTENT(IN)  :: first
    INTEGER (LongInt),                  INTENT(IN)  :: last
    INTEGER (LongInt),  DIMENSION(256), INTENT(IN)  :: pdat ! packed input
                                                            ! array
    INTEGER (ShortInt), DIMENSION(1024), INTENT(OUT):: idat ! unpacked array
!-----------------------------------------------------------------------
!   Local Variables
!-----------------------------------------------------------------------
    INTEGER (LongInt)                             :: word ! unpacked word
    INTEGER                                       :: i,j
!-----------------------------------------------------------------------

    j = 1
    DO i = first,last
        word      = ISHFT(pdat(i),-24)
        word      = IAND(word,255)
        idat(j+2) = word
        word      = ISHFT(pdat(i),-16)
        word      = IAND(word,255)
        idat(j+3) = word
        word      = ISHFT(pdat(i), -8)
        word      = IAND(word,255)
        idat(j  ) = word
        word      = IAND(pdat(i),255)
        idat(j+1) = word
        j = j + 4
    END DO

    RETURN
    END SUBROUTINE BYTESEP32
```

Appendix 4: Example of a FORTRAN subroutine to scale the MiniLidar data

```
    SUBROUTINE SCALE_MINI(bt2,iset,idat,rnge,np)  ! Scale the profile data
!----------------------------------------------------------------------
!   SCALE_MINI produces a profile of attenuated backscatter from the data
!   in IDAT using the settings in ISET
!----------------------------------------------------------------------
    USE Constants_Module
    IMPLICIT NONE
!----------------------------------------------------------------------
!   Dummy Arguments
!----------------------------------------------------------------------
    INTEGER (LongInteger) ,              INTENT(IN) :: np   ! profile size
    INTEGER (ShortInteger), DIMENSION(*),INTENT(IN) :: iset ! settings array
    INTEGER (ShortInteger), DIMENSION(*),INTENT(IN) :: idat ! data array
    REAL                  , DIMENSION(*),INTENT(OUT):: rnge ! range array
    REAL                  , DIMENSION(*),INTENT(OUT):: bt2  ! Atten. b/s
!----------------------------------------------------------------------
!   Local Variables
!----------------------------------------------------------------------
    INTEGER               :: j
    REAL                  :: A0     ! amplifier offset (V)
    REAL                  :: A1     ! amplifier gain
    REAL                  :: C0     ! offset term
    REAL                  :: C1     ! scale factor
    REAL                  :: E0     ! sample delay    (ns)
    REAL                  :: E1     ! sample interval (ns)
    REAL                  :: energy ! laser energy (J)
    REAL                  :: T0     ! sample delay    (ns)
    REAL                  :: T1     ! sample interval (ns)
    REAL                  :: PEM    ! Energy monitor output
    REAL                  :: VFS    ! Digitizer Volts Full Scale
!----------------------------------------------------------------------
!   MiniLidar parameters
!----------------------------------------------------------------------
    INTEGER, PARAMETER    :: NBITS= 8             ! digitizer bits
    REAL   , PARAMETER    :: A    = 0.13          ! receiver Area (m^2)
    REAL   , PARAMETER    :: etaO = 0.128         ! system optical efficiency
    REAL   , PARAMETER    :: con2 = 1.4989625E+8 ! light_velocity/2   (m/s)
    REAL   , PARAMETER    :: RL   = 1000.0        ! detector load (ohms)
    REAL   , PARAMETER    :: S_D  = 0.243         ! detect. sensitivity (A/W)
 !----------------------------------------------------------------------
    A0    = iset(34) * 0.001
    A1    = iset(33) * 0.01
    C0    = iset(47) * 0.1
    E0    = iset(38)
    E1    = iset(37) * 1.0E-06
    T0    = iset(16) * 10.0E-09
    T1    = iset(13) * 1.0E-09
    PEM   = iset(43)
    VFS   = iset(14) * 0.002
    energy = 0.001* (E0 + E1*PEM)
    C1     = (A1 * RL * S_D * energy * etaO * A * con2) * (2.0**NBITS)/VFS
    DO j = 1,np
        rnge(j) = con2 * ((j-1) * T1 + T0)
        bt2(j)  = (C0 -idat(j)) * rnge(j)**2  / C1
    END DO
    RETURN
    END SUBROUTINE SCALE_MINI
```

Appendix 5: Fragment of the 16-bit FORTRAN 77 subroutine used to write the data

```
    .
    .
    .
      CHARACTER*40   LocalCodePath,RemoteCodePath,
     *               LocalDataPath,RemoteDataPath

      CHARACTER * 11 DataFile
      INTEGER   * 2  size,reclw,reclb,upper,lower,irec
      INTEGER   * 2  digitiser(1024,2),lid(50,2),lidp(562),error
      INETGER   * 4  DataUnit
    .
    .
    .
         DO ichan = 1 , num_channels
             size     = 1024
             reclb    = size + 100
             reclw    = Reclb / 2
             DO i = 1 , 50
                 lidp(i) = lid(i,ichan)
             END DO

C     Compact the data into bytes

             j = 1
             DO i = 51 , reclw
                 upper   = ISHFT(digitiser(j,ichan),8)
                 lower   = digitiser(j+1,ichan)
                 lidp(i) = IOR(upper,lower)
                 j = j + 2
             END DO

C     Open the file, write data and close the file again
C     Write the data *.LID file

             OPEN(UNIT  = DataUnit,
    *             FILE  = CHARNB(LocalDataPath)//'\'//CHARNB(DataFile),
    *             ACCESS='direct',recl=reclb)             ! LID file

             IREC = SHOT_NUMBER + ICHAN - 2

             WRITE(DataUnit,rec=irec)(lidp(i),i=1,reclw)
             CLOSE (UNIT=DataUnit)

C     Write the index *.INX file

             OPEN(UNIT=DataUnit,
    *            FILE=CHARNB(LocalDataPath)//'\'//DataFile(1:8)//'INX'
    *           ,ACCESS='direct',recl=2)                  ! INX file

             WRITE(DataUnit,rec=IREC) int2(IREC)
             CLOSE (UNIT=DataUnit)

         END DO  ! (ichan = 1,num_channels)
```

Appendix 6: Example of Output of Program ReadMini

```
H:\LIDAR\MINI>readmini
Enter path to file (include trailing "\") c:\data\cgbaps\lidar\2000\sep\

Enter File number (Day of Year) (I3) 274

filename= c:\data\cgbaps\lidar\2000\sep\file274.lid

Enter record (shot) number   19

       Array  Error    Sec    Min   Hour    Day    Mth   Year   Oper   cSec
        Scan   Shot Samp-t  Input Offset  Delay    EHT detect  avg-s  avg-t
         NDf Pol/NB   Rate Channel    LPF R-gate Optical Atten Linamp Logamp
       Apert    NDc Lin-gn Lin-of Log-gn Log-of  EM-gn  EM-of Sys-con  File
         Azi     Elv Energy  Wavel S-type   Temp    Sky Samples IRrad   Alt

          34      4     57     11      0     30      9      0      2      0
           0     19     50   1000    147      1      0      4      1      0
           0      3     60      1  20000      0     30      0     64      0
          12      0    508      0  20597  17211  16250    -37      1    274
           0    900     -1      1      2      0   1476   1024   9999     95

147 148 150  43   0   7  32  58  80  98 109 117 124 129 132 137 137 136 138 141
143 143 142 141 142 144 145 145 144 143 143 145 145 145 144 145 145 145 145 146
147 148 147 147 145 146 146 145 144 144 145 147 145 145 145 145 146 147 146 147
145 146 146 144 143 144 147 147 144 144 143 145 145 145 145 147 147 147 146 145
146 149 147 145 144 147 147 148 145 148 150 149 146 146 147 148 148 148 147 145
148 149 149 149 148 144 147 148 148 146 146 144 137 132 129 129 130 133 134 136
137 138 138 139 141 143 142 143 145 147 148 148 145 147 148 147 146 147 146 145
148 147 147 147 145 147 146 147 147 147 149 148 148 147 145 147 147 149 146 148
148 147 146 146 144 145 145 147 147 149 149 148 148 147 145 146 148 148 150 150
148 147 145 145 144 148 150 150 148 148 148 149 148 148 146 147 148 150 148 148
150 150 148 148 148 150 150 147 146 146 146 149 147 148 148 148 149 149 145 147
147 147 145 147 146 148 148 148 148 145 147 148 147 147 146 146 148 147 145 147
146 146 147 147 145 144 147 147 145 145 145 145 145 148 149 148 146 147 147 147
145 147 144 145 145 148 147 147 145 150 145 149 145 147 146 148 148 148 145 146
149 149 149 147 147 148 149 147 147 147 148 147 147 147 148 150 148 148 147 148
148 149 145 145 145 146 147 146 146 148 148 148 147 146 147 148 149 146 145 147
148 150 148 147 149 150 149 148 145 146 146 148 147 147 146 147 147 147 146 146
147 148 147 148 147 147 147 145 147 147 148 147 146 148 147 148 146 147 147 145
126  77  27  24  46  72  90 104 115 123 129 133 136 137 138 140 143 143 142 142
141 143 142 143 142 144 146 148 147 148 146 148 147 146 145 144 145 147 145 144
147 148 147 145 145 147 148 147 144 145 147 148 145 145 146 146 146 145 146 144
146 148 147 145 143 147 147 148 148 146 147 148 147 145 144 146 147 148 145 145
145 147 147 146 145 148 148 147 146 147 147 147 146 145 146 148 148 146 143 146
149 150 150 148 148 148 148 147 145 143 139 138 136 136 133 136 137 139 140 139
140 144 145 144 143 146 145 145 145 147 148 149 147 147 148 148 148 147 146 146
146 147 146 146 144 146 147 148 144 145 147 146 144 145 145 147 148 148 145 145
146 147 148 147 144 148 146 145 144 145 147 146 144 146 145 145 147 147 144 145
147 147 144 145 146 146 147 147 146 145 147 148 146 145 145 145 145 145 148 149
147 149 147 146 147 147 148 147 145 147 147 148 148 148 147 147 144 145 145 148
145 146 145 147 147 149 148 148 149 149 149 149 148 145 144 146 147 146 146 146
148 149 147 148 148 149 149 148 146 146 146 148 147 149 147 150 150 150 149 148
147 147 146 145 146 149 149 148 148 148 147 149 148 148 147 148 150 150 147 148
147 148 148 149 148 149 148 147 146 148 149 149 145 146 146 148 147 148 150 148
145 147 147 145 144 147 148 150 147 146 148 148 147 147 147 148 145 144 144 146
147 150 147 147 147 148 148 147 144 148 147 149 147 147 146 148 149 150 148 148
150 148 148 149 147 148 149 149 149 150 140 105  47  23  39  61  78  97 106 117
125 130 132 135 135 140 140 140 141 143 144 144 142 142 143 146 146 144 143 144
145 148 145 143 145 147 148 145 144 146 146 148 148 146 145 149 148 146 145 148
147 146 145 145 145 148 149 148 141 145 147 147 148 146 146 149 148 145 143 145
148 151 149 146 146 146 150 144 144 145 150 151 145 146 147 150 147 147 144 148
145 149 145 146 145 150 147 143 145 147 145 145 146 146 147 147 145 147 147 145
141 139 134 129 128 131 132 134 136 138 138 140 140 142 144 145 144 144 145 147
148 148 146 147 146 147 145 144 147 147 148 147 145 148 146 147 147 146 145 148
148 150 149 147 145 147 145 148 145 147 147 148 146 146 146 146 147 144 145 147
149 148 148 148 147 148 147 147 149 150 149 149 148 145 145 146 148 148 147 146
146 148 146 146 145 147 149 149 147 145 147 147 148 148 148 150 149 150 150 148
149 149 147 146 146 148 150 149 148 149 149 150 148 147 146 146 147 148 148 149
148 147 146 146 146 147 145 148 147 147 146 148 147 147 147 149 149 147 147 147
148 150 149 148 148 150 149 148 148 148 149 151 149 148 148 151 150 149 148 148
148 147 147 146 147 148 148 148 146 147 147 147 147 147 147 148 149 149 147 148
148 147 147 146 144 146 148 148 146 146 145 147 145 147 146 147 148 148 148 147
148 150 150 148

-9.241E-11  2.218E-09  4.473E-08 -4.124E-06 -1.003E-05 -1.464E-05 -1.711E-05 -1.788E-05 -1.750E-05 -1.616E-05
-1.546E-05 -1.478E-05 -1.352E-05 -1.248E-05 -1.211E-05 -9.430E-06 -1.071E-05 -1.321E-05 -1.224E-05 -9.368E-06
-7.227E-06 -7.960E-06 -1.063E-05 -1.368E-05 -1.263E-05 -8.803E-06 -6.872E-06 -7.407E-06 -1.102E-05 -1.510E-05
-1.615E-05 -9.745E-06 -1.038E-05 -1.103E-05 -1.621E-05 -1.240E-05 -1.312E-05 -1.385E-05 -1.461E-05 -9.467E-06
-3.733E-06  2.614E-06 -4.114E-06 -4.311E-06 -1.956E-05 -1.259E-05 -1.315E-05 -2.230E-05 -3.220E-05 -3.355E-05
-2.523E-05 -6.056E-06 -2.728E-05 -2.833E-05 -2.941E-05 -3.050E-05 -1.946E-05 -7.559E-06 -2.087E-05 -8.097E-06
-3.628E-05 -2.307E-05 -2.383E-05 -5.537E-05 -7.300E-05 -5.893E-05 -1.012E-05 -1.043E-05 -6.447E-05 -6.638E-05
-8.728E-05 -5.075E-05 -5.219E-05 -5.364E-05 -5.512E-05 -1.306E-05 -1.341E-05 -1.377E-05 -3.767E-05 -6.280E-05
-3.963E-05  3.554E-05 -1.561E-05 -6.930E-05 -9.827E-05 -1.677E-05 -1.717E-05  1.171E-05 -7.788E-05  1.225E-05
 7.518E-05  4.484E-05 -5.237E-05 -5.351E-05 -2.050E-05  1.396E-05  1.425E-05  1.455E-05 -2.228E-05 -9.851E-05
 1.546E-05  5.521E-05  5.630E-05  5.741E-05  1.672E-05 -1.534E-04 -2.606E-05  1.770E-05  1.803E-05 -7.346E-05
-7.481E-05 -1.714E-04 -5.138E-04 -7.697E-04 -9.340E-04 -9.504E-04 -9.150E-04 -7.722E-04 -7.316E-04 -6.346E-04
```

```
-5.897E-04 -5.430E-04 -5.520E-04 -5.026E-04 -3.920E-04 -2.776E-04 -3.434E-04 -2.866E-04 -1.645E-04 -3.856E-05
 2.611E-05  2.651E-05 -1.750E-04 -4.099E-05  2.774E-05 -4.223E-05 -1.143E-04 -4.349E-05 -1.177E-04 -1.940E-04
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