LDAR Data Compression and Reduction Methods

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List of Acronyms

Term	Description
45 WS	45th Weather Squadron
AMU	Applied Meteorology Unit
CBT	Computer Based Training
CCAS	Cape Canaveral Air Station
CDSC	Communication and Distribution Switching Center
CGLSS	Cloud to Ground Lightning Surveillance System
CIF	Central Instrumentation Facility
CSR	Computer Sciences Raytheon
EOM	End Of Mission
GB	Gigabyte
GIF	Graphical Interchange Format
GSFC	Goddard Space Flight Center
HP	Hewlett Packard
JSC	Johnson Space Center
KB	Kilobyte
Kbps	Kilobits per second
KSC	Kennedy Space Center
LAN	Local Area Network
LDAR	Lightning Detection And Ranging
LDM	Local Data Manager
LLP	Lightning Location and Protection, Inc.
MB	Megabyte
Mbps	Megabits per second
McIDAS	Man computer Interactive Data Access System
MIDDS	Meteorological Interactive Data Display System
NWS MLB	National Weather Service in Melbourne, Florida
ROCC	Range Operations Control Center
RSA	Range Standardization and Automation
RTLS	Return To Launch Site
RWO	Range Weather Operations
SMG	Spaceflight Meteorology Group
SSEC	Space Science and Engineering Center
TIFF	Tagged Image File Format
USA	United Space Alliance

1. Introduction

The purpose of this report is to document the Applied Meteorology Unit's (AMU) findings from the investigation of data reduction methods for LDAR (Lightning Detection and Ranging) system output. LDAR data are not currently available to the Spaceflight Meteorology Group (SMG) at Johnson Space Center (JSC) because the volume of data output from LDAR is, at times, too large for both transmission through current communication lines and timely ingestion and display by MIDDS (Meteorological Interactive Data Display System). As a result, SMG is the only weather office supporting the space shuttle program that does not have access to the real-time LDAR data.

All data collected in the Kennedy Space Center (KSC) / Cape Canaveral Air Station (CCAS) area are transmitted to SMG through MIDDS at the Range Operations Control Center (ROCC). MIDDS is the principle meteorological data display system for both SMG and the 45th Weather Squadron (45 WS), and an auxiliary display system for the National Weather Service in Melbourne, Florida (NWS MLB). In addition, because these data cannot be ingested and displayed in MIDDS they are not available to the MIDDS users for data integration and overlay displays nor are they archived for case post-analysis.

The operational needs of the 45 WS are such that immediate display of LDAR signatures as they are detected is necessary to provide timely warnings for ground operations personnel. NWS MLB also needs immediate display of the data for convection initiation and dissipation determination, aviation forecasts and advisories, and timely severe weather warnings. The operational needs of SMG require timely but not immediate display of LDAR events to aid in the evaluation of shuttle landing weather flight rules for both RTLS (Return To Launch Site) and EOM (End Of Mission) landings.

Immediate display of the data at the 45 WS and NWS MLB is now provided by the current LDAR display. Since the operational needs of the 45 WS and the NWS MLB are met, LDAR data reduction techniques to facilitate ingest into MIDDS are primarily needed for SMG to access the data. However, making the LDAR data available in MIDDS will benefit the 45 WS and NWS MLB in two ways: 1) An LDAR display can be built that can be integrated with other data displays and 2) An archive of LDAR data can be created that uses much less storage space than would currently be possible.

This study focuses on two different data reduction approaches:

- Data compression techniques which preserve all data content and
- Data filtering techniques which remove data yet preserve information content and allow development of an LDAR display which is less data intensive than the current display.

The remainder of Section 1 describes the LDAR system and MIDDS, their data and display input and output capabilities, and a summary explaining the need for data compression/reduction. Section 2 describes communication line issues and proposes possible data compression and reduction methods with options for display of LDAR data which are less data intensive than the current LDAR display. Section 3 discusses the advantages and disadvantages of implementing each method, and Section 4 contains the report summary and conclusions.

1.1 LDAR System Description

The LDAR system is composed of a network of seven sensing antennas installed over an area that includes KSC and CCAS. These antennas detect electromagnetic pulses centered at 66 MHz (5 - 6 MHz bandwidth), which is the frequency strongly emitted by lightning. The location (x, y, and z) and time (t) of each LDAR event is determined based on the time of arrival of a signal at a combination of four of the sites. At least two site combinations are used to confirm the location of each event. Since several events can be detected along individual strokes, the volumetric extent of both intracloud and cloud-to-ground lightning can be determined (Maier *et al*. 1995).

1.1.1 LDAR Display

The LDAR display is currently available to personnel at KSC in Room 334 of the Central Instrumentation Facility (CIF) building, the Range Weather Operations (RWO) and the AMU in the ROCC on CCAS, and NWS MLB on dedicated workstations. It is also available to KSC personnel on the KSC video system. The three dimensional LDAR display, shown in Figure 1-1, is comprised of four panels in which each LDAR data point is represented. The X-Y (horizontal or plan view) panel in the lower left, the X-Z panel (altitude versus east/west) in the upper left, and the Y-Z panel (altitude versus north/south) in the lower right display the location of each event. The histogram panel in the upper right reveals the number of events that occurred in a given minute for the current minute and the previous four minutes. The right-most column in the histogram represents the data in the current minute and increases in height as LDAR events are detected, transmitted, and received.

The LDAR system also ingests and displays the lightning locations observed by the 45 WS's Cloud-to-Ground Lightning Surveillance System (CGLSS) manufactured by Lightning Location and Protection, Inc. (LLP). The CGLSS location coordinates are converted to LDAR coordinates and transmitted with the LDAR data. The locations are indicated by red X's at the surface level in each of the data location display panels.

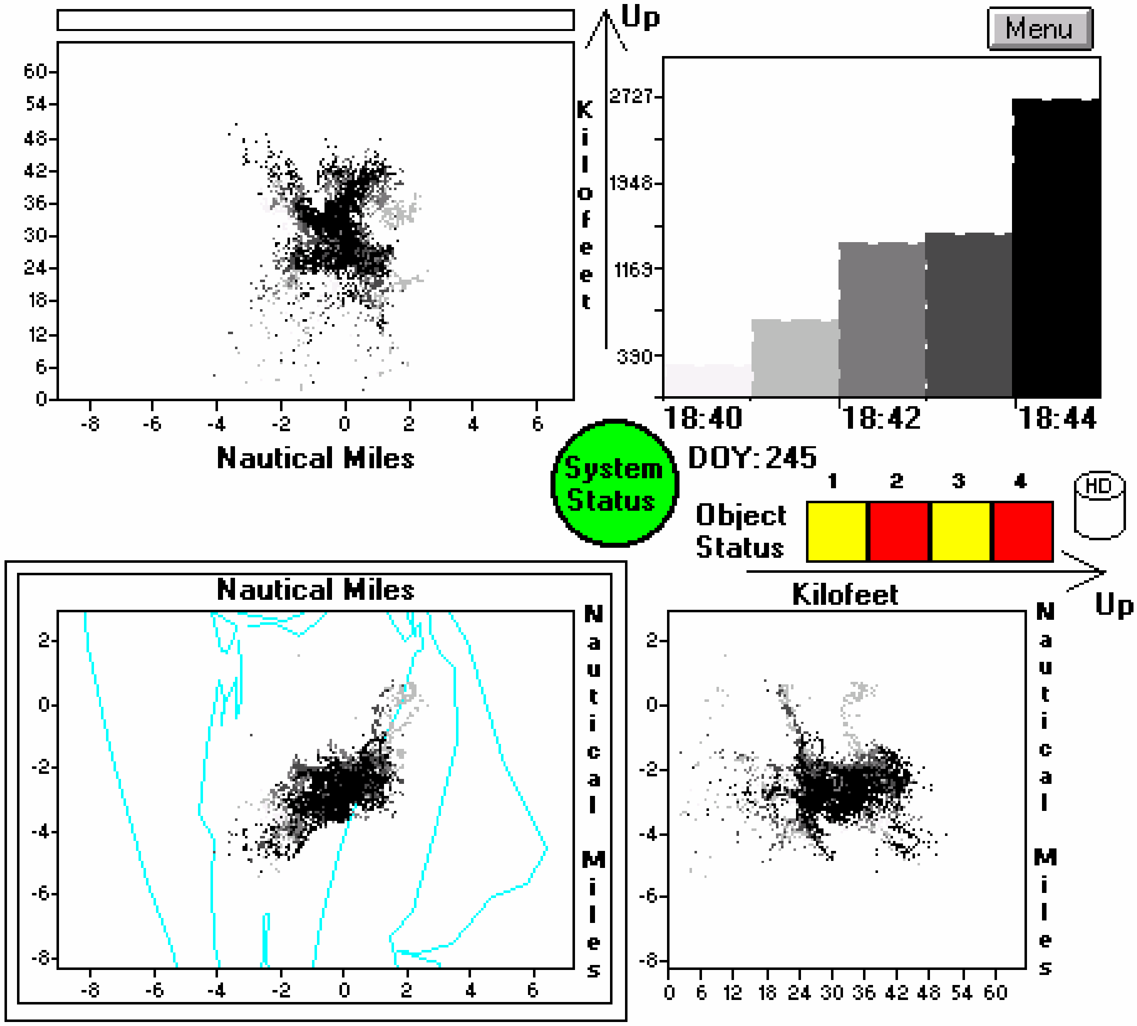

Figure 1-1 Example of the LDAR display from the AMU's LDAR CBT (Computer Based Training). CGLSS data are not shown in this display.

1.1.2 LDAR Data

Real-time LDAR data events are recorded in two types of packets that are 64 and 22 bytes (8 bits/byte) in length (LDAR Certification Document, 1995). The 64-byte packet contains information, such as the time of arrival and peak detected signal amplitude at each site, that is valuable for system quality checks, trouble shooting, and research. These packets are only transmitted when the data are being monitored for these purposes. Much of this information is not needed for data display and would needlessly slow down the display system. Therefore, these data are filtered into 22-byte packets such that only the information needed for display (Table 1-1) are sent. The information in each display packet includes the status code (if LDAR, LLP, or bad data), time of arrival at the central site (in hours, minutes, seconds, and microseconds), Julian day, and the three-dimensional coordinates (x, y, and z) in meters. The 22-byte packets are sent in real time whenever the LDAR and CGLSS systems locate an event. Both types of packets are transmitted on the communication line at the same time when the 64-byte packets are being accessed.

Table 1-1 Format of LDAR event 22-byte packet.	
Byte Number	Byte Description
1	Status (LDAR, LLP, bad)
2	Hour
3	Minute
4	Second
5 - 8	Microsecond
9 - 10	Julian Day
11 - 14	X Coordinate (meters)
15 - 18	Y Coordinate (meters)
19 - 22	Z Coordinate (meters)

The LDAR system is capable of processing 3500 - 6000 events/s at a sustained rate depending on the number of site combinations used in locating each event, and can process a burst rate of 9700 events/s as long as the average rate does not exceed the aforementioned sustained rates. LDAR has been observed to detect 1000 - 2000 events/s for several minutes from intense storms which produced a great amount of lightning. As much as 50 Mbytes of data in a half hour (average 1300 events/s) and 1 GB a day (average 500 events/s) have been produced from these events. The real-time data are transmitted to each display location at KSC, the ROCC (RWO and AMU), and NWS MLB on separate dedicated T1 communication lines which are capable of transmitting 1.544×10^6 bits per second (or 1.544 Mbps). It is important to note that when the 64 byte packets are being monitored, the Mbps rates given are increased by a multiple of 3.9. Thus, a 2000 event/s detection rate would produce a 1.36 Mbps data processing rate which results in the requirement of a dedicated T1 communication line. Table 1-2 shows the transmission rates for the real-time 22-byte data and when the 64-byte data are included for the LDAR event detection rates just discussed.

LDAR event packets for the previous four minutes are filtered in the display workstation to contain only the point information and are, therefore, approximately 12 bytes in length. Using the smallest and largest observed rates in the paragraph above, as much as 2.1 - 8.4 Mbytes of data must be processed for display in each of the three event location panels and in the histogram panel in the user workstation every minute. It is a known and documented problem that the display is unable to keep up with high data detection rates (LDAR Certification Document, 1995). An internal data buffer stores the incoming data while the previous four minutes' data are being redrawn. If there are more incoming data than can be stored in the buffer during the redraw period, a certain amount will be overwritten and not displayed. The amount of incoming data lost is dependent upon the data rate, workstation speed, and workstation random access memory.

Table 1-2 Transmission rates based on LDAR event detection rates. The transmission rates were calculated using 8 bits/byte.			
LDAR events per second	Kilobytes (KB) per second for 22-byte data	Transmission Rate for 22-byte data	Transmission Rate including 64-byte data
500	11	.09 Mbps	.351 Mbps
1000	22	.17 Mbps	.663 Mbps
1300	28	.22 Mbps	.858 Mbps
2000	44	.35 Mbps	1.36 Mbps
3500	77	.62 Mbps	2.42 Mbps
6000	132	1.1 Mbps	4.29 Mbps
9700	213	1.7 Mbps	6.63 Mbps

1.2 MIDDS Description

The MIDDS uses the Man computer Interactive Data Access System (McIDAS) software, developed by the Space Science and Engineering Center (SSEC) at the University of Wisconsin, to display meteorological data for operational analysis and forecasting. Users are able to display local wind tower, profiler, radar, satellite, upper air, surface observational, and forecast model data at terminals that are connected to an IBM mainframe computer. IBM mainframes exist at both SMG and the ROCC and are connected by communication lines through which SMG is able to access both the raw data and MIDDS products created from that data.

The present MIDDS is in the process of being replaced at the 45 WS. The new display system is being developed by PRC, Inc. and is known as Advanced McIDAS. This system operates on Hewlett Packard (HP) UNIX workstation platforms and will have file formats based on an Informix data base format rather than the current McIDAS formats. The change is expected to be complete by the end of 1997. The Range Standardization and Automation (RSA) effort is also planning a change in the data display system for the 45 WS, but the exact timing and outcome is unknown at this time.

The principle display system for SMG is also being replaced by a version of McIDAS developed by SSEC for HP UNIX workstation platforms known as McIDAS-X. This change is expected to be complete by July 1997. The files needed to display the data will be in a similar format to those used in the current MIDDS. Because the Advanced McIDAS data files will have completely different formats than those in MIDDS, SMG will not be able to use the Advanced McIDAS files in their system. In addition, the possible changes proposed by RSA may also result in a system which uses file formats that are incompatible with McIDAS-X. SMG is, however, currently able to access most of the raw data files from the KSC/CCAS measurement systems. They are then able to create the files locally needed by their display system.

1.2.1 MIDDS Display Capabilities

Data in MIDDS can be displayed in text, graphic, or image formats. The data are displayed from one of four McIDAS file types: area, meteorological data (MD), grid, and ASCII text. Area files are generally used for the display of satellite, radar, and other remotely sensed data images. MD files contain point source data such as that from station observations, profilers, wind towers, and rawinsondes. These files are used in the generation of vertical profiles, listings, and contoured analyses, and are used to generate some grid files. Grid files are used to display geographically distributed data either from the interpolation of data from MD files or from numerical model output. A text file contains any meteorological bulletin in text format. MIDDS also has a data overlay capability that allows more than one data type to be displayed at the same time.

The McIDAS-X display capabilities and file formats will be very similar to those in the current MIDDS. The main improvements are an increased displayed image size (due primarily to larger monitors), a user friendly graphical user interface (GUI), and a multiple window display capability. The same can be said for the new Advanced McIDAS at CCAS, except that the data file formats will be different than the current McIDAS formats, as just described. It will have a utility that will be able to convert an area format file to the appropriate format needed by the new system. This utility will be important in one of the data reduction methods discussed in Section 2.

1.2.2 MIDDS Data Ingest Capabilities

The current communication line between MIDDS at the ROCC and SMG transmits data at the rate of 224 Kbps (28 Kbytes/s). Regardless of the ingest capability of the new McIDAS-X at SMG, this is the maximum rate at which it will receive data from the system at the ROCC through which LDAR data will likely be transmitted. SMG is able to access the raw data from the current MIDDS, and will retain this capability with the future Advanced McIDAS.

Both MIDDS and the future Advanced McIDAS require that raw data be received by software routines called ingestors before being processed for display. Individual ingestors are required for each data type. They are installed on hardware that may or may not be dedicated to the ingest of only one data type. Some may have the capability to ingest data at higher than the T1 rate. Once data are received by their ingestor, they must be processed and written in a format that is readable by MIDDS before they are ready for display. This does not allow for immediate display of the data, but, for most data types, the timeliness of the display is sufficient.

1.3 LDAR Data Transfer and Display Issues

The current communication line data transfer rate of 224 Kbps between the ROCC and SMG is insufficient for the transfer of unmodified LDAR data at the observed rates discussed earlier, even though the current MIDDS and future Advanced McIDAS at the ROCC are capable of ingesting data at that rate. KSC, the ROCC (RWO and AMU), and the NWS MLB receive LDAR data through dedicated T1 lines and display the data on dedicated DEC-Alpha workstations using the standard NASA-developed display. This is an option for SMG and will be discussed in Section 2.

In order to transmit the data through the current communication line to SMG, a data compression or reduction routine must be employed. This will not allow for immediate display of the data, but a one to two minute delay in display of the data due to processing and transmission is sufficient for SMG (Tim Oram, personal communication). Unfortunately, an approximate delay time cannot be determined because none of the techniques suggested in this report have been tested on real-time LDAR data. Consideration must be given to how the data are processed for transmission, i.e. how many algorithms are needed, and how many systems (e.g. computers) the data must pass through before reaching their final destination at a display workstation in SMG.

2. Discussion of Possible Solutions

There are two communication line possibilities for transmitting LDAR data to SMG. The first is to install a dedicated T1 line from the LDAR system to SMG, and the second is to use the current 224 Kbps line between SMG and the MIDDS at the ROCC. The methods needed to use either of these lines are discussed in this section, which is divided into two sections. Section 2.1 discusses the issues surrounding the transmission of LDAR data to SMG via a T1 communication line. Section 2.2 describes the steps that must be taken if the current 224 Kbps communication line is to be used.

2.1 T1 Communication Line to SMG

In order for the LDAR data to be transmitted to SMG with no data reduction or compression, a T1 communication line would have to be purchased and installed on the LDAR communication system in the Communication and Distribution Switching Center (CDSC) on KSC. As the discussion on LDAR data in the previous section indicates, the amount of data the system is capable of detecting dictates that the T1 line be dedicated to the transmission of LDAR event data. After the purchase and initial setup, the company that owns the particular telecommunications line or satellite link being used to transmit the data will charge a monthly fee. The charge is based on the distance of transmission and would currently cost between $5000 and $6000 per month between KSC and JSC, or $60000 to $72000 per year (Mr. Seaton Norman, Goddard Space Flight Center (GSFC), personal communication).

In addition to the purchase, installation, and maintenance of a T1 line, other equipment must be purchased and installed in order to display the data. The data can be displayed either in the new McIDAS-X system or on a dedicated workstation. If the data are to be displayed in McIDAS-X, hardware must be installed to ingest and store the data until they can be displayed on the existing workstation network. Software to convert the data from its raw form into a format that can be read and displayed in McIDAS-X must also be developed. Because McIDAS-X ingests, processes, stores, and displays several other data types, display of the LDAR data may be delayed beyond the one to two minute period specified by SMG. The use of a dedicated workstation would likely facilitate more timely display of the LDAR data. This would require the purchase of a workstation and hardware to receive the data. Very little software development would be needed as the software already exists that reads, ingests, and displays the data.

2.2 Current Communication Line to SMG

If a dedicated T1 line is not chosen as a solution, the only other possibility is to send the LDAR data to the MIDDS at the ROCC where it can be ingested for transmission across the current 224 Kbps communication line with the other data sets received by SMG. Use of this line requires that the data be processed by compression or filtering routines and written to files before transmission.

The T1 line that transmits the LDAR data to the ROCC comes into the AMU. From there it is converted to an ethernet and split into two lines which go to the AMU and RWO display workstations. It is possible to extend this line from the RWO workstation to the location in the ROCC where all data sets are ingested. Hardware and software to ingest and process the data at the ROCC would have to be purchased and developed. The hardware should include a computer processor similar to the DEC-Alpha workstations currently in use for LDAR display with as much memory and storage space as economically possible for data processing and archiving. Personnel who maintain the MIDDS have suggested that two ethernet cards be installed within the processor that would not allow the MIDDS and LDAR system to communicate or interfere with each other. One ethernet card would be connected to the ethernet line transmitting the LDAR data. The other ethernet card would be connected to a second ethernet line that would have access to the processed data and transmit them to the location (currently an HP 735 workstation) where the communication line to SMG would have access to it.

The processor could be the RWO display workstation or a completely separate processor that does not contain the display software but only the software to compress or reduce the data. If the existing workstation is to be used, it would have to be upgraded or replaced with equipment that can display and process the raw data at the same time while maintaining the level of timely display currently available.

The data transfer method currently used to transmit data along this line will only transfer 80 character per line ASCII format files. Processed LDAR data files may be very large, especially during intense periods of lightning, and should be in binary format to ensure that they are the smallest size possible for timely transmission. Furthermore, if the files have been reduced in size by a compression routine they will be in the format the routine creates. Personnel at SMG are currently investigating the possibility of procuring and installing the Unidata Local Data Manager (LDM) that will transfer files in almost any format. This will most certainly have to be done because the processed LDAR data will not be transmittable with the current method. It must be noted that, no matter which data transfer method is used, the LDAR data must be written to files before they are transmitted instead of transmitting a data stream as is done in the current LDAR system.

2.2.1 Data Compression Methods

A data compression routine should retain all information in the data yet reduce the volume. Two methods for compressing the data are given in this section. The first discusses the possibility of data compression, and the second describes the steps needed to capture and transmit LDAR image files.

2.2.1.1 Compression Routines

LDAR data are written in binary format. Data can be easily read or written in ASCII or binary format, but binary format allows for a much more efficient use of disk space and memory than ASCII. Therefore, LDAR data already use the least amount of disk and memory space possible while still being easy to read and write in data processing and display routines.

If a data compression routine is employed before transmission, the data would have to be uncompressed after transmission in order to be accessed and displayed by the display software. As SMG does not require immediate display of the data, a delay due to this processing may not pose a problem. The main issue in choosing a particular compression routine over another is the amount of compression achieved. The data file must be sufficiently compressed such that it can be transmitted with other data sets across the current communication line.

Several experts in the area of computer programming and data compression and transfer were consulted regarding the compression and transmission of LDAR data files created from the high rates discussed in the previous section. None were aware of compression routines that could reduce the LDAR data by the amount needed for transmission, but all stated that tests with the 22-byte packet data would have to be conducted to be assured of an answer. The 22-byte packet data are not currently being archived except at user request. Research is continually being done to find efficient ways of compressing and decompressing large data sets such that their information can be used in a timely manner (Pen-Shu Yeh, Code 738 GSFC, personal communication). If this becomes a desired solution, the search for an appropriate compression/decompression routine should be continued.

The steps outlined in Section 2.2 describing the transmission of the data through the current communication line would be followed if a compression method is chosen. The compression software would be located in the computer processor into which the real-time LDAR data are ingested. A new file should be opened at the beginning of each specified time period (e.g. one minute) and filled with the data detected during that time period. Once the file is closed it can be compressed and made available for transmission to SMG. A method to decompress the file must be located in a computer processor at SMG in order for the data to be displayed. Once decompressed the current display software can be used to display the data, or personnel at SMG may choose to build another type of display for their use.

2.2.1.2 Image Capture

An image capture routine does not compress and preserve the raw data, rather it captures the image that was created with the raw data. Over the course of five minutes, as many as 6×10^5 events can be displayed (based on 2000 events/s) which is approximately equal to 8.4 MB (see discussion in Section 1.1.2). The size of an image file would depend on the format. It should be smaller than a display of the raw data and essentially make available all LDAR data that are displayed. This method requires several steps before it can be implemented.

A decision on the image format would have to be made. The HP workstations at SMG are able to display GIF (Graphical Interchange Format) image files, though currently not in the McIDAS-X environment. Presently, a routine which creates an LDAR display image file in Targa (*.tga) format is available (Launa Maier, personal communication). This routine can be modified to create GIF image files that would be on the order of 100 KB, much smaller than 8.4 MB. The GIF image file could be sent to SMG with no other modifications. Another method for getting the image file into McIDAS-X would be to convert the image file from the captured format into a McIDAS area file format. A software routine to convert a TIFF (Tagged Image File Format, or *.tif) file into an area file exists, and would have to be modified to convert from other image formats. Area format files can be displayed by McIDAS-X, but not by the new Advanced McIDAS. Although Advanced McIDAS will not be able to read area files, it will be able to transform them to a format that it can read. Therefore, the 45 WS and NWS MLB, as well as SMG, will be able to display the image on their systems.

Software to automatically capture the image should be written to avoid problems that can be created from manual capture by personnel, such as not capturing the image at the proper moment or not having time to capture the image due to other responsibilities in times of severe or potentially severe weather. The LDAR display is updated every minute. Therefore, an image should be created every minute once all the data within that minute and the preceding four minutes have been displayed. This step can be done in one of two ways: the software could be used only on the workstation from which the image will be captured, or it could be made available on all LDAR display workstations so that image files could be created locally at each workstation. A ‘switch’ should be added to the software so the automatic capture could be turned off. This would allow operational personnel to choose whether or not images are saved and to stop automatic image capture when there is no activity.

An LDAR display workstation must be chosen that will be used for image capture. There are two options for capturing an image at a workstation: 1) capture the displayed image and 2) create a virtual image in memory. In the first option, a particular image configuration would have to constantly be displayed on the chosen workstation (i.e. image center lat/lon, zoom, etc.). This will ensure that the image will not be inadvertently modified and will ensure consistency in the image sent to SMG. Because of this requirement, the dedicated workstation chosen cannot be used operationally. Another workstation with a monitor for the display would have to be purchased. In the second option, a particular image configuration would also have to be chosen, but the display would be created in memory, rather than displayed on the monitor, and captured as a GIF image file. This will allow the displayed image to be modified without changing the format of the captured image. To ensure that virtual image capture does not interfere with the operational display, it should be done on a workstation with enough memory to be able to create both the displayed image and the virtual image. The files could be transported through the connections described in Section 2.2.

2.2.2 Data Filtering Methods

Data filtering reduces data volume by removing certain portions of the data. Any filtering technique used with the LDAR data should sufficiently reduce the volume of data while retaining enough information for the data to be useful to operational forecasters. This section describes two similar data reduction methods referred to in this report as the data volume and data density methods.

2.2.2.1 Data Volume Method

In this method, the atmosphere would be divided into discrete volumes by creating a three-dimensional grid centered at the LDAR central site. The size of the grid should be a compromise between data resolution needed by operational personnel and the amount of data reduction needed for timely ingest and display. A smaller grid size would produce a higher resolution display, but a larger grid size would further reduce the volume of data. Resolutions on the order of 500 m in the horizontal and 100 m in the vertical have been suggested. The present operational temporal resolution is one minute (except for the current minute in which events are displayed as they are detected) and is the suggested resolution for this method, although this can also be defined based on operational and data reduction needs.

Each grid volume would have a simple 'on/off switch' (e.g. the characters 'y' and 'n' or integers '1' and '0') that would indicate whether LDAR events occurred within the volume. As LDAR events are detected over the period of one minute, their x,y,z locations would be used to determine which grid volumes contain data and their 'switches' would be turned on. This would be done without regard to the number of LDAR events in a given volume. Once a switch is on within a volume, no other action for that volume need be taken.

Rather than transmitting every individual LDAR event (22 bytes/event), this method reduces data volume by transmitting one value (~2 bytes) with its associated x,y,z (4 bytes each, 12 bytes total) information to represent the existence of lightning in a particular volume. Approximately 14 bytes per volume per time period would replace a larger number of bytes that depends on the number of LDAR events in a particular volume during the specified time period. In order to maximize the reduction, data from grid volumes that do not contain LDAR events would not be included in the data stream. Thus, the amount of data produced depends on the three-dimensional spatial extent of the lightning in existing cells as opposed to the lightning intensity (i.e. number of LDAR events). For instance, more LDAR events may be detected in a small intense cell than in a large but weaker line of cells. The amount of data produced using this method would be less overall than the raw data in both cases, and would likely be less for the small cell.

The steps outlined in Section 2.2 describing the transmission of the data through the current communication line will be followed if this method is chosen. The algorithms that produce the grid volumes would be located in the computer processor into which the real-time LDAR data are ingested. A new file should be opened at the beginning of each time period and filled with the data produced by the algorithms during that period. The file can then be closed and made available for transmission to SMG. New display software would have to be designed to display the data in their new form. The display could be similar to the current LDAR display and use a marker, such as the 'x' used currently, to designate the locations of the grid volumes on the display in which lightning has occurred.

2.2.2.2 Data Density Method

The method described in this section is currently being developed by NASA personnel (Launa Maier, personal communication) and is very similar to the data volume method. It divides the atmosphere into volumes that are 500 m in the horizontal and 100 m in the vertical in a three-dimensional grid centered at the LDAR central site. The temporal resolution is one minute. Different spatial and temporal resolutions may be tested, but the final resolutions will be based on operational needs and the amount of data reduction required.

The number of data events per volume per minute, or data density, is determined in this method. As an LDAR event is detected, its x,y,z location will be used to determine the grid volume in which it belongs, then a counter for that grid volume will be incremented. At the end of one minute the number of LDAR events along with the x,y,z grid volume location (approximately 14 bytes/volume/minute) will be available for transmission as opposed to the individual events (22 bytes/event). As with the data volume method, data from grid volumes that do not contain LDAR events would not be included in the data stream. Again, the amount of data produced depends on the three-dimensional spatial extent of the lightning in existing cells as opposed to the lightning intensity (i.e. number of LDAR events).

It is often the case that the number of LDAR events in adjacent grid volumes will vary by several orders of magnitude. Linear contours are insufficient to characterize this range of LDAR densities. To produce a meaningful display, these data density values are normalized by taking the logarithm (base 10) of the value and multiplying it by 10. Colors are assigned to different ranges of 10log values and a colorfill routine is used to display the data (Figure 2-1). This display is very similar to a radar reflectivity display with more intense areas of LDAR events represented by warm colors and less intense areas represented by cool colors which allows forecasters to see where lightning is most intense and to determine if a cell is intensifying or decaying. Because the data values and not the color display are transmitted, the end-users may also choose to contour the LDAR data for overlay on other products such as radar and satellite imagery.

The steps outlined in Section 2.2 describing the transmission of the data through the current communication line will be followed if this method is chosen and will be exactly as those described in the previous section on the data volume method (Section 2.2.2.1).

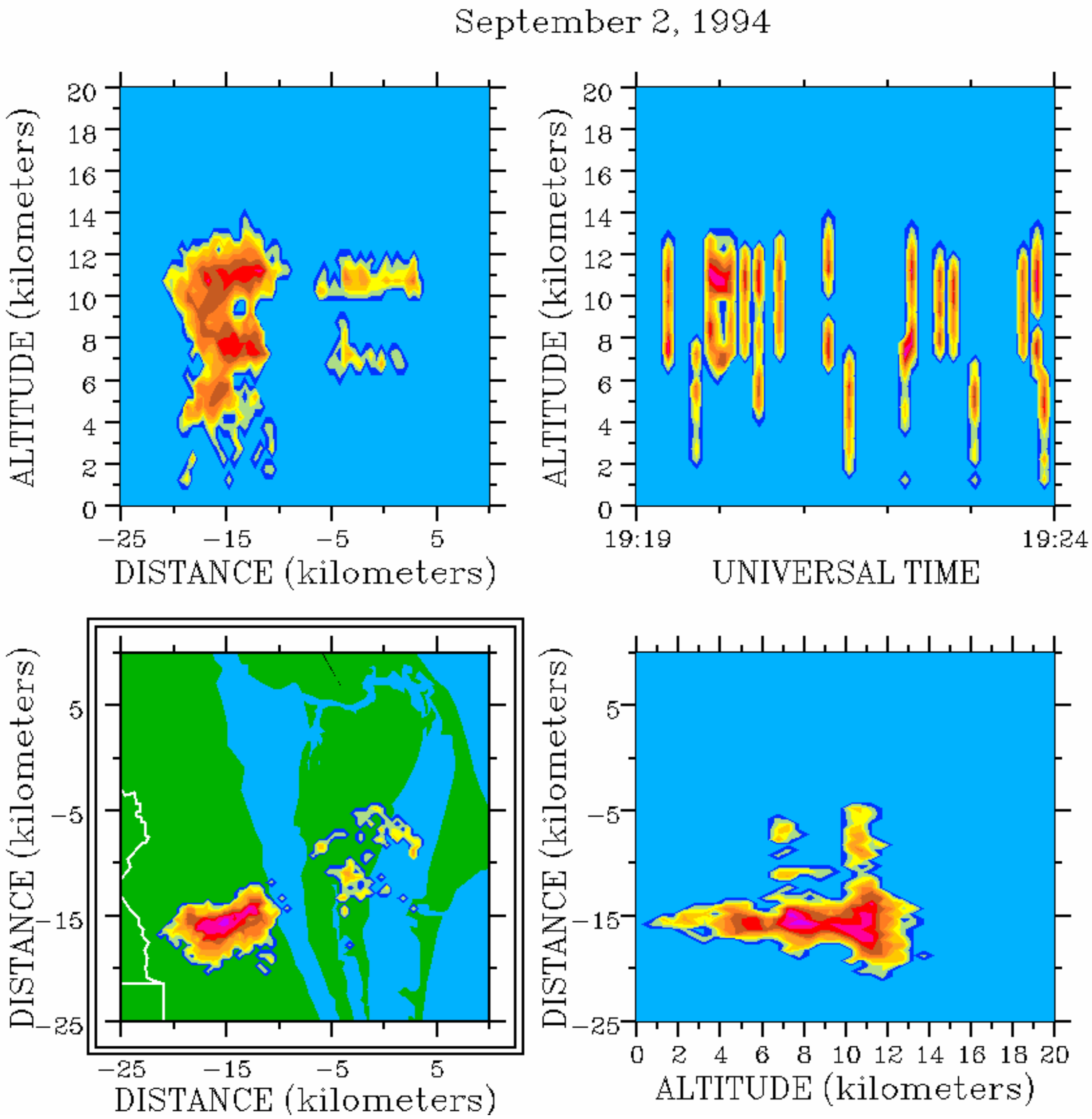

Figure 2-1 Example of the data density display showing LDAR event intensities over the 5 minute period from 19:19 to 19:24 UTC on 2 September 1994. The upper left image is the X-Z panel, the lower left image is the X-Y panel, the lower right is the Y-Z panel, and the upper right is the time-height profile of LDAR event densities. The distance in kilometers on the X-Y, X-Z, and Y-Z panels is from the LDAR central site. An intensity scale is not provided.

3. Discussion of Advantages and Disadvantages of Each Method

The advantages and disadvantages of each data compression and reduction method described in Section 2 are discussed in this section.

3.1 T1 Communication Line to SMG

Advantages:

The use of a dedicated T1 line to transmit LDAR data to SMG would result in no data loss and a minimal delay in the display of LDAR events as they are detected. Personnel in SMG could build the LDAR display from the existing display software or develop a new display to meet their operational needs. Any delay in display of the data would be due to transmission of the data and not due to data processing for compression or reduction prior to transmission.

Disadvantages:

The monetary cost for this option is high. There are two basic components that must be purchased, depending on how the data will be ingested and displayed. These components include the T1 line itself and either a data ingestor and buffer if the data are to be displayed in McIDAS-X, or a dedicated DEC-Alpha workstation for data display. The cost also includes all associated hardware and labor needed for installation of these components, as well as a monthly charge by the company that maintains the telephone lines. The monthly charge for a T1 line between KSC and JSC could be as much as $5000 - $6000, which is quite costly considering that the LDAR data detection rates that require T1 transmission only occur several days per year. Finally, because of the large volume of LDAR data during intense storms, all the components mentioned would have to be dedicated to the transmission, ingestion, and display of LDAR data only. When there is no lightning, the line would not be used at all.

If a dedicated workstation is used for display, this would increase the number of different display devices for SMG personnel to monitor. Both the 45 WS and SMG wish to consolidate all data displays into one display device. A dedicated LDAR display workstation would create a new display to monitor instead of reducing the number of display devices.

3.2 Current Communication Line to SMG

Advantages:

All data sets would be consolidated in one system and transmitted across one line. This would eliminate the need to maintain two communication systems as would happen if a dedicated T1 line were purchased and installed. Also, the existing display systems (MIDDS, McIDAS-X, and Advanced McIDAS) can be used to display the data.

Disadvantages:

In order to transmit LDAR data across the current communication line, it must be processed in some manner causing a further time delay in displaying the data at SMG. The amount of time needed for processing depends on the routine used, and tests may be needed to determine which would sufficiently reduce the data volume for transmission to SMG with all other data sets.

3.3 Compression Routines

Advantages:

The advantage to using a data compression routine would be that SMG would receive all LDAR event data across the present communication line, assuming a routine exists that could compress the data to that extent. SMG would then be free to build a display similar to the current display or manipulate and display the data in other ways to meet their operational needs.

Disadvantages:

A suitable routine has not yet been found to sufficiently compress the data such that they can be transmitted across the current communication line with all other data sets. Tests must be conducted using the 22-byte event data to find an appropriate routine. If one is found, there may be other issues involved such as the purchase of hardware or software necessary to use the routine.

3.4 Image Capture

Advantages:

There is essentially no data loss with this method as the standard LDAR image is captured with all events displayed. The HP workstations at SMG have several utilities that allow them to display GIF image files. A routine to capture the LDAR display in Targa format exists in the LDAR system and can be easily modified to capture the display as a GIF image. A captured image file can also be transformed into a file that is readable by MIDDS. A routine currently exists that transforms TIFF (*.tif) images to area images that could be modified for other image formats (including Targa and GIF). The file size is typically much smaller than the volume of data used to build an LDAR display (~100 KB vs. ~8 MB), especially during intense periods of lightning, and is small enough to be sent through existing communication lines and displayed in a timely manner.

An added advantage with this method would be the development of an algorithm that could automatically capture images every minute at the workstation level. If made available to each LDAR display workstation, an option to switch from the automatic to manual capture should be added so that operational personnel are able to control which images are captured. Manual and automatic capture would be useful to forecasters for case post-analysis and presentation preparation.

Disadvantages:

The operational personnel using McIDAS-X to view LDAR output would have no control over the display configuration. Although a convention for the display configuration should be agreed upon prior to implementation, operational personnel may wish to view other configurations as the meteorological conditions change. Due to the need for a consistent image, a non-operational workstation would need to be dedicated for image capture. The non-operational workstation would not allow personnel with access to that workstation to modify the display.

Although routines exist that can capture LDAR images and convert the image files to area files, these routines would have to be modified for automated image capture, conversion, and storage in the McIDAS-X area format.

3.5 Discrete Volumes

Advantages:

The volume of data using the discrete volume method would be smaller than using the LDAR point data, with the extent of reduction depending upon the three-dimensional extent of the lightning during the specified time period. The data can be displayed in the current MIDDS, future Advanced McIDAS, and McIDAS-X. SMG and the 45 WS can build displays similar to the current LDAR display or in other formats that would meet their operational needs. The display would be much less data intensive than the current display and could easily be used in data overlay routines.

A data processing routine would have to be written to convert the point data to discrete volumes, however the processing time would likely be minimal. Once it is determined that LDAR events exist in a grid volume, no other processing is needed.

Disadvantages:

The foremost disadvantage to this method would be the amount of information lost. The grid element dimensions obviously play a role in this loss, but more importantly no information would be given about the number of LDAR events in a given grid element. Operational personnel would know that lightning has occurred in a certain area but would not know the intensity. The horizontal dimensions should be chosen to cause minimal loss of location information. Since the three-dimensional accuracy of LDAR event locations is approximately 300 m, dimensions on the order of 500 m would be appropriate. There is also a loss of time resolution with this method as the data are provided at the end of every time period (e.g. one minute) instead of instantaneously.

Data processing routines to create the discrete volume information from individual LDAR events, calculate the 10log values, and convert the discrete volume data into a format compatible with MIDDS, Advanced McIDAS, or McIDAS-X do not exist and would have to be developed.

3.6 Data Density

Advantages:

The volume of data using the data density method would be smaller than using the LDAR point data, with the extent of reduction depending upon the three-dimensional extent of the lightning during the specified time period. The data can be displayed in the current MIDDS, future Advanced McIDAS, and McIDAS-X. As with discrete volumes, SMG and the 45 WS can build displays similar to the current LDAR display or in other formats that would meet their operational needs, and the display would be much less data intensive than the current display.

This display would be familiar to operational personnel as it is similar to a radar reflectivity display. Areas of more intense lightning can be distinguished from areas of less intense lightning through the use of a colorfill routine (see Figure 2-1). Contours of intensity could also be created and would be ideal for use in data overlay routines.

Finally, the algorithms for this display are being developed by NASA personnel. Modifications necessary to make the algorithms suitable for operational use are being developed.

Disadvantages:

As with discrete volumes, there will be a certain amount of data loss which would depend on the grid element dimensions chosen. Although intensities will be known, the exact location of LDAR events will not. This loss of information will decrease as grid dimensions decrease, but the dimensions must remain large enough for sufficient data reduction. However, since the three-dimensional accuracy of LDAR event locations is approximately 300 m, the use of 500 m horizontal dimensions currently used in this method should cause minimal loss of location information. There is also a loss of time resolution with this method as the data are provided at the end of every time period (e.g. one minute) instead of instantaneously.

Data processing routines to create the data density information from individual LDAR event, calculate the 10log values, and convert the density data into a format compatible with MIDDS, Advanced McIDAS, or McIDAS-X do not exist and would have to be developed.

4. Summary and Conclusions

Several methods of transmitting LDAR data to SMG have been presented in this report†. These methods can be divided into two communication line categories: 1) Transmit the raw data to SMG by connecting another T1 line to the LDAR system, and 2) Transmit the data across the current 224 Kbps communication line. If the first category is chosen as the solution, a T1 line would have to be purchased and maintained at a substantial cost. However, there would be a timely display of the full-resolution data. If the second category is chosen, the data would have to be compressed or reduced to the extent that they can be transmitted with other data sets with little or no delay. Processing the data will cause a delay in the transmission and, therefore, display, but it may still be timely enough for SMG's operational needs.

While no processing of the data is required if a T1 line is purchased, four methods which preprocess the data allow use of the current communication line and are described in Section 2. They are

- The use of a data compression routine,
- An LDAR image capture routine,
- A discrete volume routine, and
- A data density routine.

The data must also be transported to the location where the communication line can have access to them on the current MIDDS.

MIDDS maintenance personnel suggest that the best way to accomplish this is to extend the T1 line that transmits the LDAR data to the ROCC. It should be extended to the location in the ROCC where the MIDDS resides. A computer processor would have to be purchased for LDAR data ingest and processing. Another communication line would connect the processor to the location where all raw data are stored and where the 224 Kbps line is connected.

The most important decision to be made is which reduction routine to use. Consideration must be given to the amount of reduction achieved so that the LDAR data can be transmitted with other data, the processing time of the routines to ensure timely display of the data, and what data format will be most valuable to operational personnel.

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† After this study was completed, Capt. Scot Heckman of the 45 WS suggested that another data processing method be explored. This method should display and archive individual lightning flash information from the LDAR event data. The request for such a display and archive stems from the need to verify lightning advisories and to determine which flashes affected the launch pads and vehicles. A lightning advisory is issued when lightning is expected to occur within 5 nm of specified areas on KSC and CCAS. Cloud-to-ground strikes can be easily verified with CGLSS data. Cloud-to-cloud and cloud-to-air flashes can only be verified by deriving them from the LDAR data which are not easily retrieved from the archive.

The two data filtering methods described in this report, data volume and data density, will provide information on electrical discharges that occurred over the advisory areas within a certain time period and can be used to verify the advisories. However, these methods do not resolve the individual flashes and cannot be used to identify flashes that affect launch pad operations.

As this method has not been analyzed, it is not certain how or if it can be done. One possibility would be to store the locations of the endpoints of lines that would define individual flashes. Another would be to store the minimum number of LDAR events needed to define a flash. If the task of including LDAR data in the MIDDS is pursued, the possibility of creating this type of derived product display and archive should be addressed.

The focus of this study has been on how to make LDAR available to SMG. If the data are processed and made available on the Advanced McIDAS, it will benefit the 45 WS and NWS MLB in two ways. First, it will allow displays to be built which can be integrated with other data sets and, secondly, it will allow the archive of LDAR data that uses much less storage space than the current LDAR archive.

5. Acknowledgments and References

Most of the information in this report was not documented and had to be gathered through meetings with experts on the relevant topics. As a result, this section is divided into two sections. The first acknowledges the personnel that provided undocumented information, and the second provides standard document references.

5.1 Acknowledgments

There are four main topics on which data had to be gathered. These topics are outlined below with the personnel who provided information on the topic and a brief statement about the information provided.

<u>*LDAR System Information:*</u>

- **Ms. Launa Maier** of NASA/KSC provided information regarding all aspects of LDAR system concerning data format, data transmission, and data display.
- **Mr. Clark Pinder** and **Mr. William Roeder** of the 45 WS provided information on the operational requirements of the 45 WS concerning LDAR data display.
- **Mr. Tim Oram** and **Mr. Tim Garner**, both of SMG, provided information on the operational requirements of SMG concerning LDAR data display.
- **Mr. Steve Hodanish** of NWS MLB provided information on the operational requirements of NWS MLB concerning LDAR data display.

<u>*MIDDS/McIDAS-X/Advanced McIDAS Information:*</u>

- **Mr. Russ Bolton** of Computer Sciences Raytheon (CSR) provided information regarding all aspects of the MIDDS and Advanced McIDAS concerning data format, data transmission, and data display.
- **Ms. Patty Shelton** of PRC, Inc. provided information on MIDDS and Advanced McIDAS data ingest and display capabilities.
- **Mr. Bryan Batson** of the United Space Alliance (USA) and **Mr. Tim Oram** provided information on all aspects of the McIDAS-X concerning data ingest and display.

<u>*Data Communications Issues:*</u>

- **Mr. Bryan Batson** and **Mr. Tim Oram** provided information on the communication line and data transfer protocol between the ROCC and SMG.
- **Mr. Russ Bolton** provided information on how to transmit the LDAR data from the T1 line to the MIDDS/Advanced McIDAS in the ROCC.
- **Mr. Seaton Norman** of GSFC provided information on the cost of installing and maintaining a T1 line between KSC and JSC.

<u>*Data Compression/Reduction Information:*</u>

- **Ms. Launa Maier** provided information for the data density method and provided the image for Figure 2-1 in Section 2.2.2.2.
- **Dr. James Tilton** of Code 935 and **Mr. Pen-Shu Yeh** of Code 738 at GSFC NASA discussed the possibility of data compression and expressed an interest in testing their routines on LDAR data.

5.2 References

Maier, M., C. Lennon, T. Britt, and S. Schaefer, 1995: Lightning Detection and Ranging (LDAR) system performance analysis. Preprints, *Sixth Conference on Aviation Weather Systems*, Dallas, TX, Amer. Meteor. Soc.

Lightning Detection and Ranging (LDAR) Certification Document, 1995, NASA/KSC, Ground Engineering Directorate, Information Systems Division.