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# LDAR, a Three-Dimensional Lightning Warning System: Its Development and Use by the Government, and Transition to Public Availability

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## Abstract

NASA, at the John F. Kennedy Space Center (KSC), developed and operates a unique high precision lightning location system to provide lightning related weather warnings. These warnings are used to stop lightning-sensitive operations such as space vehicle launches and ground operations where equipment and personnel are at risk. The data is provided to the Range Weather Operations [45<sup>th</sup> Weather Squadron, U. S. Air Force (USAF)] where it is used with other meteorological data to issue weather advisories and warnings for Cape Canaveral Air Station (CCAS) and KSC operations. This system, called Lightning Detection and Ranging (LDAR), provides users with a graphical display in three dimensions of 66 MHz radio frequency events generated by lightning processes. The locations of these events provide a sound basis for the prediction of lightning hazards. NASA and Global Atmospheric, Inc. are developing a new system that will replace the unique LDAR components with commercially available and maintainable components having improved capabilities. These components will be phased in to ensure full continuity and access to this important warning technology. These LDAR systems are expected to eventually be available for installation and use by the public at specialized facilities, such as airports, and for general weather warnings via the National Weather Service (NWS) or television broadcast. The NWS in Melbourne has had access to real-time LDAR data since 1993 on an experimental basis. This use of LDAR has shown promise for the improvement of aviation forecasts and severe weather warnings. More so, it has opened the door to investigate the feasibility of issuing lightning-related public advisories. The success of its early use suggests that this technology may improve safety and potentially save lives, therefore

constituting a significant benefit to the public. This paper describes the LDAR system, the plans and progress of these upgrades, and the potential public benefits of its use.

## Introduction

John F. Kennedy Space Center (KSC) operations emphasize safety. The combination of Florida's frequent thunderstorms and the hazardous and expensive equipment involved in space flight operations requires strict attention to lightning hazards. Lightning can ignite propellants, induce damaging voltages and currents in critical circuitry, and injure or kill personnel. KSC and the USAF Eastern Range (ER) have experienced significant lightning induced system failures including the double lightning strike to the Apollo 12 Saturn V launch vehicle, which almost aborted the second moon landing mission in 1969; significant damage to the Viking 1 orbiter spacecraft while inside a processing facility in 1975; and the triggered strike to and subsequent loss of Atlas Centaur AC-67 launch vehicle in 1987. As a result of these and other experiences, a major emphasis is placed on proper facilities protection, the real-time monitoring of lightning hazards, and the cessation of sensitive operations when lightning activity is occurring in the vicinity. These safety rules require systems capable of measuring atmospheric electrical potentials and accurately locating lightning events.

Lightning, and clouds posing the threat of lightning, in the KSC/CCAS area are monitored using 6 separate systems, including a "field mill" network which measures atmospheric electric potential gradients near the ground, the National Lightning Detection Network (NLDN), a local equivalent of NLDN called Lightning Location and Protection (LLP), a 5-cm weather radar (WSR-74C), a 10-cm Doppler weather radar (WSR-88D), and the Lightning Detection and Ranging System (LDAR), described here, for locating and displaying radio pulses produced by lightning events. Based on input from these systems, especially LDAR, KSC lightning safety policy dictates that personnel are warned of lightning events occurring near the KSC area and that specific operational and personnel controls are established when lightning is detected within 5 miles of an operational area.

KSC developed and operates the LDAR system, which receives and detects radio pulses emitted during lightning events and locates each pulse in local east, west, and height coordinates. It operates on the principle of hyperbolic position location. In this scheme, the difference between times of arrival of a signal received by two separated radio receivers indicates that the source lies on a hyperbolic cone centered on the baseline joining the two receivers. A hyperbola is defined as a curve such that for any point on the curve, the difference in distances between that point and two fixed foci is a constant. This constant is the difference in times of arrival multiplied by the speed of light. By establishing a number of baselines, each one producing a hyperbolic cone, the intersection of these cones gives the estimated position of the source.

LDAR was developed by Carl Lennon, a former NASA engineer, and others in the mid-70's to support lightning research activities taking place in the KSC area. The LDAR system was upgraded several times to support research objectives and came to be unofficially relied upon to determine lightning risks to KSC operations. In the early 90's, Mr. Lennon and Launa Maier established the LDAR system as operational and it

has become an integral part of the weather warning system at KSC and CCAS. The LDAR system is operated and maintained for NASA by Command Technologies Inc. (CTI) based in Satellite Beach, Florida.

### **LDAR System Description**

The LDAR system has 7 VHF radio receivers (66-MHz center frequency, 6-MHz bandwidth), one at the central site, and 6 on a roughly 10-kilometer circle (see figure 1). The receivers form two Y-shaped arrays laid interlaced with each other in opposite senses forming a star shape. Each remote site includes an LDAR receiving antenna, a logarithmic RF amplifier, and a 4.4-GHz microwave line-of-site link back to the central site. The log amp results in much higher dynamic range, but also minimizes amplitude differences and rectifies the signal (i.e., all signal values are positive with no zero crossings). At a pre-established signal level, the central channel triggers a recording of 81.92 microseconds of data from all 7 channels. Each data stream is sampled at 100 MHz with 8-bit resolution. The peak amplitude time tag is determined from each channel and corrected for the known time delay due to the microwave transmission link. The time of arrival from each remote site is subtracted from that of the central site and used to form two solutions of location, one for each Y-shaped array. If the range along the ground for two solutions agree to within 0.35 km when the determined range is less than 7 km, or if they agree to within 5 percent of the range beyond 7 km, the solution is declared valid. If not, a voting procedure involving all 20 combinations of sites is implemented which compares the horizontal range solutions. If at least 7 of the combinations agree, then the solution is declared valid.

The heart of the LDAR system is the Timing Interface Unit (TIU) which performs the triggering, analog to digital conversion, data buffering, peak finding and differencing of time of arrival between the detected peaks of each channel. There are two TIU's for redundancy with manual switchover between them. The existing TIU's are wire wrapped VME boards consistent with the fabrication of a prototype system rather than an operational system. The circuitry and system software is unique and uses hardware and firmware systems that are now obsolete, so finding personnel familiar with the basic system approach is becoming very difficult.

The TIU provides the differences of time of arrival for a specific event to the location processors. These DEC Alpha machines compute the x, y, z locations of each detected event. A voting algorithm described above is used to provide an estimate of the source location or to reject the event. This voting scheme results in rapid analysis of incoming data, as many as 6,000 events per second, so that detection, location, and display can occur in near real time. The system, however, discards about 60 percent of detected events due to low vote count. This is thought to be due to a combination of factors, including the use of peak value rather than waveform matching to determine DTOA's, the long-time constant of the RF system which results in a smoothing of peaks, the logarithmic signal amplification which increases dynamic range but also smoothes peak differences, the change in order in time of events measured at widely separated locations, the non isotropic emission of RF from the sources resulting in wide variations in intensity at different locations, and the nonlinear nature of the LDAR equations resulting in sign errors in x and y coordinates.

The accepted position solutions, in x, y, and z coordinates (east, north, up), are provided to a display processor which sends a video output to the KSC Operation Television System on Channel 43, available throughout KSC and Cape Canaveral Air Station. In addition, the digital data are sent by T-1 lines to Range Weather Operations at CCAS and to the NWS office in Melbourne, Florida which have full-function LDAR workstations for the preparation of weather warnings and advisories. A representative image of lightning activity as provided by the real time display processor is shown in figure 2. The display is not static but replays the events detected over the previous 5 minutes with increasing brightness as the most recent events are displayed. This short replay is repeated each minute to give the viewer a sense of the storm activity dynamics. Display panels are provided for the east/west location of events and the east/up location of events which indicate both the overall movement of the storm activity and as an indicator of the probability for ground strikes. In addition, a histogram provides a plot of the number of detected events versus time to indicate the trend in strengthening or weakening of activity. Other indicators provide time, date, and system health information.

### **LDAR Upgrades**

In order to reduce the operation and maintenance costs of LDAR and make the benefits of the technology available to the general public, NASA has entered into a Space Act Agreement with Global Atmospheric, Inc. (GAI) for the development of a commercial LDAR system. This Agreement requires both parties to contribute efforts to the development and testing of new systems intended to enhance the operational concepts of LDAR and provide systems that are lower in cost, more easily manufactured, easier to maintain, and have a longer technology life. Global Atmospheric has a long track record of developing and implementing lightning detection and location technologies and has a series of products in operation and in the process of installation worldwide. In addition, the company possesses core expertise in lightning electromagnetics and signal detection, processing and compression technologies. NASA's intent is to foster the development of technology to replace the existing LDAR system components and facilitate the delivery of technology to the public that will significantly enhance public safety.

Under this agreement, GAI will replace the one-of-a-kind signal processing hardware (TIU) with a commercially viable mass produced equivalent which incorporates improvements based on NASA's experience with the current configuration. The commercial system may also include cost-cutting changes in the sensor array geometry, antennas, signal transmission, and display components of the system to improve its commercial viability. NASA is providing a test-bed capability for the new system components and will help GAI compare data from the new systems with that from the online LDAR.

GAI has already received LDAR-type data from a data collection system, operated by Dynacs, that gathers the raw LDAR signals but at a higher data sampling rate and not in real time. Using this data, GAI has developed and demonstrated innovative approaches to signal analysis that will facilitate their approach to the hardware digital signal processing system in the TIU. The LDAR operations contractor, CTI, has provided GAI with two DEC Alpha computers, configured as an LDAR location

processor and display processor, which have been used to perform end-to-end tests of the TIU using recorded LDAR data. GAI has installed the TIU prototype and DEC machines at KSC in parallel with the LDAR system for evaluation. This evaluation is ongoing and planned to continue into the summer of 1998.

NASA, through Dynacs Engineering Inc., the Engineering Development Contractor, is also developing an innovative system which could reduce the required number of remote LDAR stations. The current system has 6 remote sites, each with an LDAR antenna, receiving electronics, and a line-of-sight microwave link back to the central site. Maintaining this equipment in remote locations is time consuming and sometimes, given Florida's wildlife, hazardous. Carl Lennon, the original developer of LDAR, conceived of a small version of LDAR, located at the central site, which would reliably indicate the direction of arrival of a lightning pulse. NASA installed a prototype system, a Y configuration of antennas with 90-meter baselines and is developing algorithms to perform real-time angle measurement. Given that three variables are required to locate an event, either x, y, and z or azimuth, elevation, and range, this Short Baseline LDAR will provide two of the three variables needed to unambiguously locate an event. This data can be mixed with the data provided by LDAR or used as a quality control measure. From a practical standpoint, the benefits of a Short Baseline system include a higher acceptance rate, increased accuracy, and, potentially, the ability to build future LDAR systems with fewer remote sites. This has benefits, not only in reduced equipment acquisition and maintenance costs but, also, reduced real estate and associated costs. There may also be locations where it is not possible to site 6 remote stations. This year, Dynacs plans to design and build a Short Baseline TIU, including a real-time data processor to digitize four channels of VHF wide-band data at a sampling rate of 500 MHz and perform real-time cross correlation and position solutions. An innovative and fast algorithm was developed to perform real-time azimuth and elevation solutions using least squares techniques.

### **LDAR Applications in the Public Sector**

Lightning detection and location systems are currently used for various public-sector interests. They have become necessary and integral for providing insight into the presence of electrical activity associated with convective storms, especially over gap locations not covered by the traditional network of weather radars. Research meteorologists have been analyzing such data over the past decade hoping to find clues which might indicate tornadic thunderstorms or other forms of severe weather. Thunderstorm-day climatologies are now being translated into updated climatologies of flash density. Perhaps the overall popularity can be best exemplified by its acceptance and use by many television weathercasters who now provide certain population groups with lightning information.

However, these systems and the data they provide are of much lower location accuracy than LDAR, while only concentrating on the higher intensity events of cloud-to-ground discharges. Lower intensity events, such as in-cloud or cloud-to-cloud events, which make up a predominate part of a thunderstorm's electrical character, go undetected. The NLDN covers an extremely large geographic area, but is of less value for providing local forecasts and warnings. Under a joint National Weather Service and

NASA experiment, the digital output from the LDAR location processor is sent to NWS Melbourne (MLB), which has a full-function LDAR workstation at its disposal. The intent is to explore the potential utility of LDAR to support NWS's efforts in the protection of life and property of all citizens of east central Florida from the effects of hazardous weather.

NWS MLB has outlined a three-pronged approach in assessing LDAR's utility as it relates to aviation forecasting, severe thunderstorm discernment, and public advisories. LDAR information is used to optimize the first-period usage of "TS" (thunder) and "VCTS" (vicinity thunder) in Terminal Aerodrome Forecasts (TAF's) for the airports located in Orlando, Daytona Beach, Melbourne, and Vero Beach. Specific rules have been outlined requiring forecaster reaction when LDAR events are detected within 5, 10, or 20 nautical miles from each of the respective runway complexes. In the realm of severe thunderstorm discernment, MLB has been using LDAR information to improve the probability of detection (and warning lead time) scores of pulse-severe storms which often result in damaging microburst winds. Together with researchers from Massachusetts Institute of Technology (MIT), MLB analysis has shown merit in tracking LDAR flash rates associated with specific convective cells, as well as tracking rapid increases in LDAR rates, for discerning potentially severe storms from non-severe storms.

Finally, MLB has embarked on an attempt to address lightning as a direct and advisable weather hazard. Lightning annually kills more people in Florida than any other weather hazard, but the availability of total lightning data, the frequency of individual lightning events, and the large geographic areas of responsibility have been problematic issues which have thwarted previous attempts at establishing effective warning systems. LDAR has given MLB forecasters an advantage and has opened the door to explore the inclusion of lightning information within public (NOWCAST) products and eventual public advisories. MLB has already used LDAR to support the 1996 Summer Olympic soccer venue in Orlando as well as other outdoor festivities. With LDAR, the potential CG discharge is often evident during those critical periods of first and last strikes or when lightning may travel greater distances from the parent storm channeled through charged cloud or cloud debris. The NWS Southern Region Headquarters has recently endorsed a project which has enabled MLB to explore creative avenues of informing the public of impending lightning hazards. This project, called Enhanced Lightning Information and Services Experiment (ELISE) has, as one of its stated objectives, determining if NLDN data alone is sufficient for providing enhanced lightning services.

With the next generation of LDAR, commercial applications will initially be concentrated within the research community and the early customers are likely to be universities, government, government laboratories, and a few private research organizations. As costs come down and the value of the three-dimensional data becomes more well known and understood, the commercial application may extend into broadcast meteorology and lightning hazard detection for large private facilities sensitive to lightning hazards, such as the respective tourist attractions near Orlando. The creation of derived products will further facilitate its usefulness.

## Conclusions

LDAR has been shown to be highly useful to the spacecraft launch community in reducing the hazards associated with lightning activity through a combination of effective detection and display technologies coupled with an effective lightning advisory system. NASA and the USAF are taking steps to improve the usefulness of LDAR and reducing its operating costs by cooperating with a major commercial developer of lightning warning systems to jointly make available improved LDAR component technology. Not only will this development effort make more cost-effective warning systems available to the government, it is expected to facilitate the commercial success of these technologies and make them available to a broader public. The joint venture between NASA and GAI is well on its way with highly innovative components developed and under test at KSC. Several avenues are being investigated to provide technical improvements that will reduce the number of remote detection stations or otherwise dramatically improve costs. Potential users of LDAR-based systems must also gather experience with the technology and develop effective procedures for its use. The technology also has the potential to enhance the meteorologist's capability to assess severe weather hazards including the potential for microbursts. Important experience has already been acquired by meteorologists and has shown that airport weather forecasts and public weather warnings can be enhanced through this technology. GAI expects the first commercial system to be available in late 1999 or the following year.

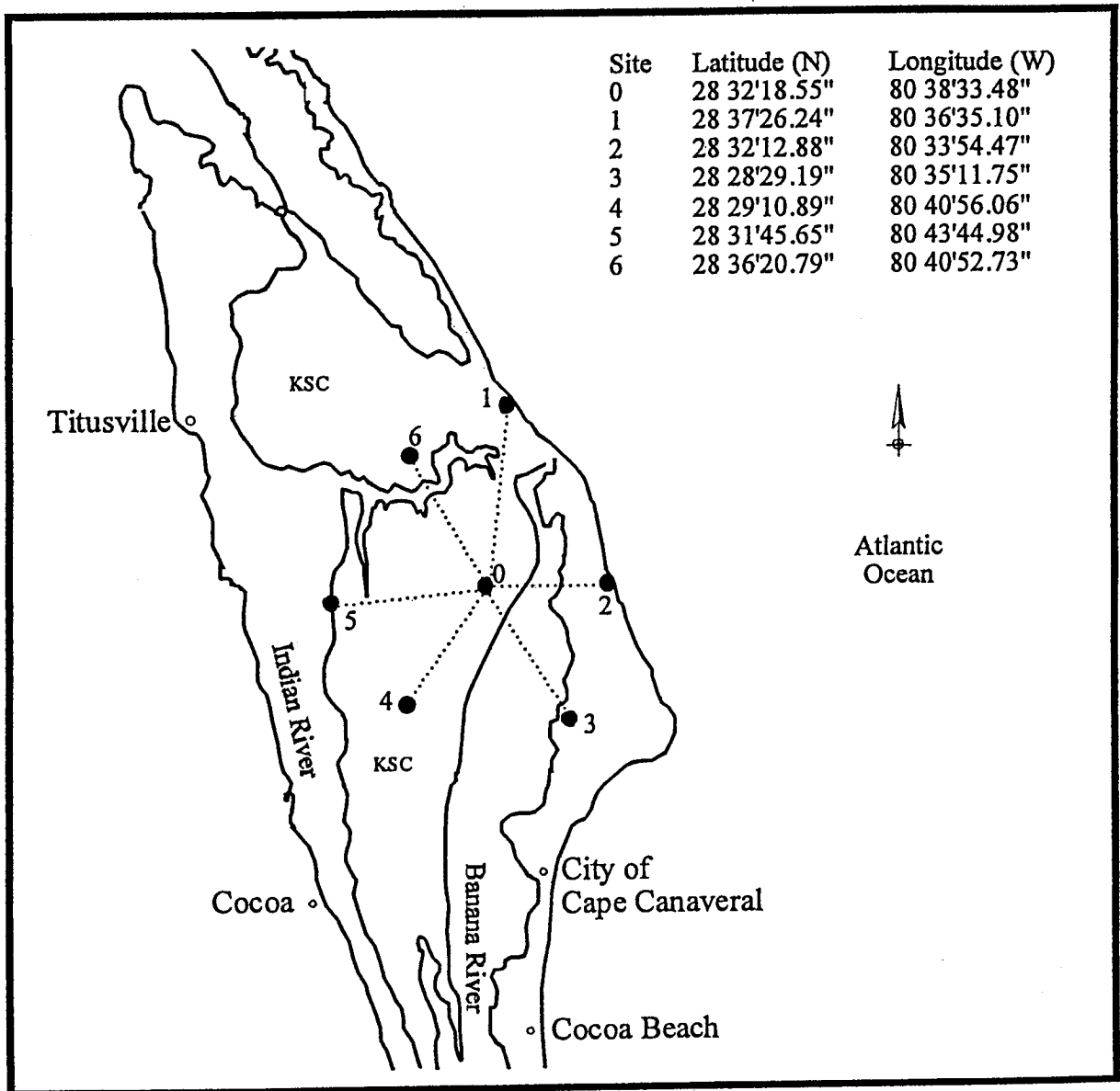


Figure 1. LDAR Site Locations Showing the Central Site (0) and the Remote Sites



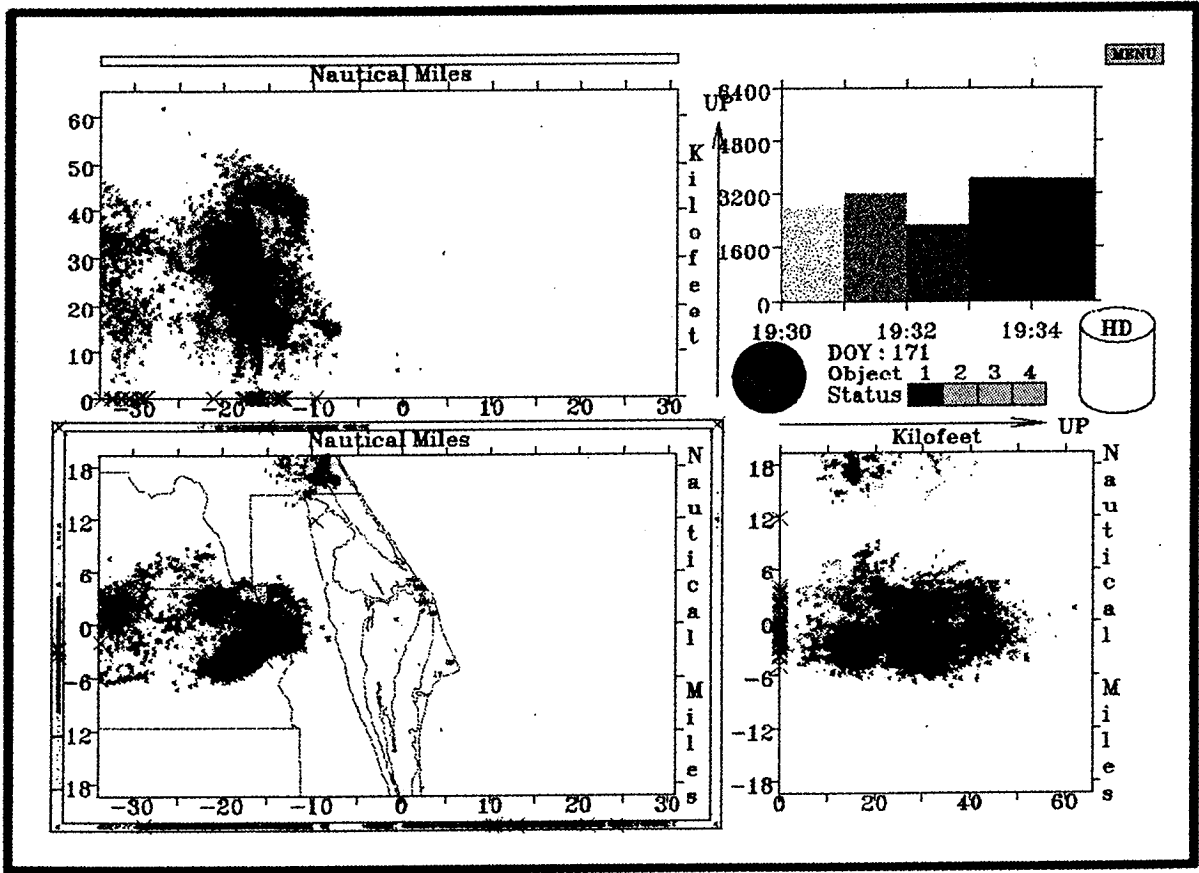


Figure 2. A Representative Image of Lightning Events Displayed by the LDAR System