HOUSTON LDAR II NETWORK: OPERATION, PERFORMANCE AND INITIAL RESULTS

Brandon L. Ely, Richard E. Orville, and Lawrence D. Carey

Texas A&M University
College Station, Texas

1. INTRODUCTION

The Houston LDAR II network is an array of twelve VHF time-of-arrival (TOA) sensors. The LDAR II sensors were purchased by the Texas A&M Department of Atmospheric Sciences from Vaisala Inc. to examine the total lightning structure of thunderstorms and conduct in-depth studies into the effects a large metropolitan region has on thunderstorm electrification (Orville et al. 2001; Steiger et al. 2002). The sensors are functionally similar to the New Mexico Institute of Mining and Technology's Lightning Mapping Array (LMA) described by Rison et al. (1999). These systems are based on the original Lightning Detection and Ranging (LDAR) system developed at NASA's Kennedy Space Center (Lennon and Maier, 1991).

VHF TOA systems map lightning in three dimensions by detecting short impulses of VHF radiation. By accurately measuring the time of arrival of the VHF pulses at several sensors and based on the fact that VHF signals propagate along line-of-sight, these pulses can be modeled as point sources in three dimensions. Each sensor records the time and amplitude of the largest amplitude pulse during a 100 μs interval. This gives the network the possibility of detecting a maximum of 10,000 sources every second.

2. NETWORK SETUP AND OPERATION

The Houston LDAR II network has been operational since mid July of 2005 with at least seven sensors and has been archiving lightning data since August 1, 2005. By mid-August, the number of sensors increased to the current configuration of the Houston LDAR II network (Fig. 1) with ten operational sensors. The center of the network is located at 29.79°N and 95.31°W, which is slightly northeast of downtown Houston. The network has an average sensor baseline of 25 kilometers and a network diameter of 80 kilometers. Each sensor is tuned to a 5 MHz band with a center frequency that varies between 69.0 and 71 MHz (upper edge of TV channel 4) depending on RF noise conditions at each site.

Real-time data from the sensors is transmitted to Texas A&M for thunderstorm warning, research case selection, and to monitor and fine-tune the LDAR sensors. The real-time data is transmitted to the central workstation through a wide variety of Internet connections, from DSL to T1 lines. Due to the limited data rates at several of the sites, the sensors are configured to transmit the strongest VHF pulse during every 200 ms interval, essentially decimating the data by 50%. This reduces the maximum possible number of sources per second to 5,000 and cuts the maximum data rate in half to a manageable 300 kbps.

Each LDAR II sensor has the capability of storing the non-decimated (100 μs resolution) to a hard disk at the sensor site. The raw data is physically retrieved every other month and

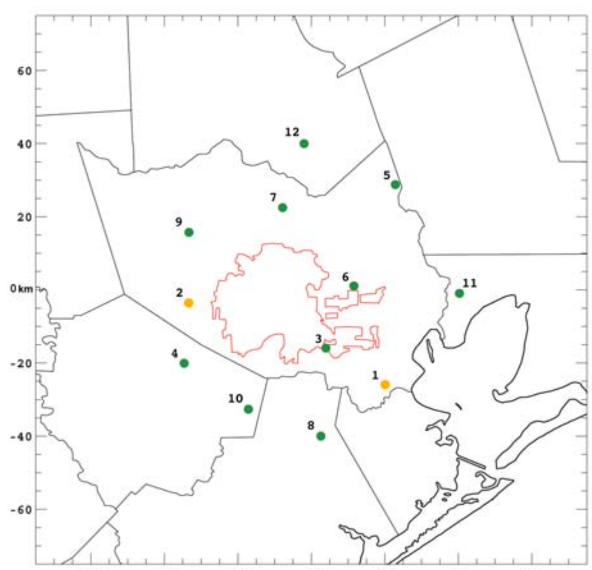

Figure 1. Map depicting the locations of the twelve Houston LDAR II sensors. The green sensors are currently installed and functioning and the orange sensors are currently offline and/or not installed. The red outline shows the Houston Urban area and industrial suburbs.

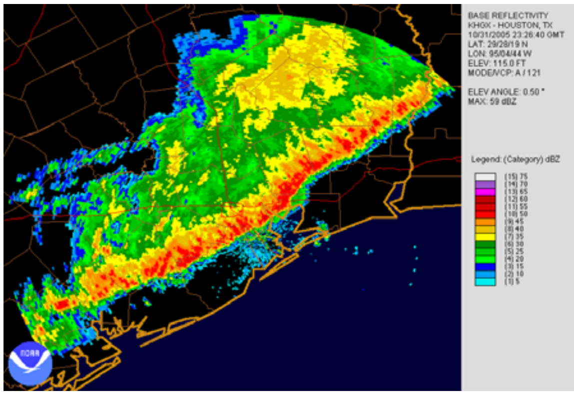

Figure 2. Composite reflectivity scan from the NWS WSR-88D at League City (KHGX) on October 31, 2005 at 23:26 UTC.

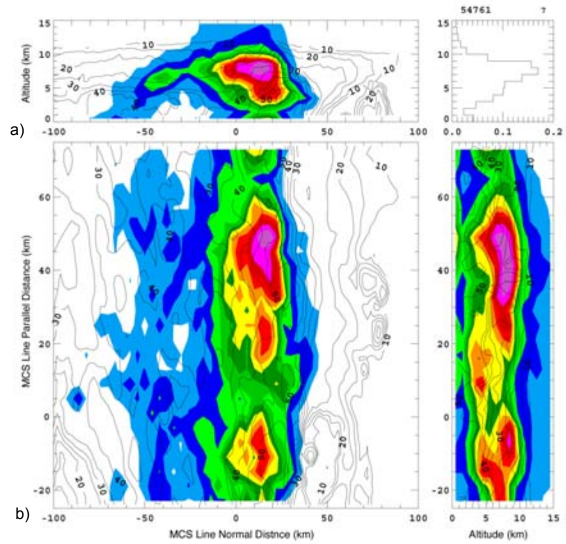

Figure 3. LDAR lightning source density (color filled contours) and KHGX composite radar reflectivity (unfilled contours) overlays of three orientations: A) MCS Line Normal vs Altitude, B) MCS Line Parallel vs MCS Line Normal, and C) MCS Line Parallel vs height. LDAR lightning sources cover a ten minute period centered on the KGHX radar scan at 23:26 Z.

processed to provide the highest quality dataset for research analysis. In the event that a hard disk fails and non-decimated data for a sensor is lost, the real-time decimated data for that sensor can be incorporated into the research dataset to partially replace the data that were lost.

3. FIRST RESULTS

The first test of the current ten sensor network configuration came on October 31, 2005. An intense squall line ahead of a strong cold front propagated from the panhandle region of Texas, through Houston, and into the Gulf of Mexico. Figure 2 shows the League City WSR 88D (KHGX) composite reflectivity as the squall line passed over the center of the LDAR network at 23:26 UTC. The system maintained this intensity throughout its traversal across the coverage area of the Houston LDAR II network.

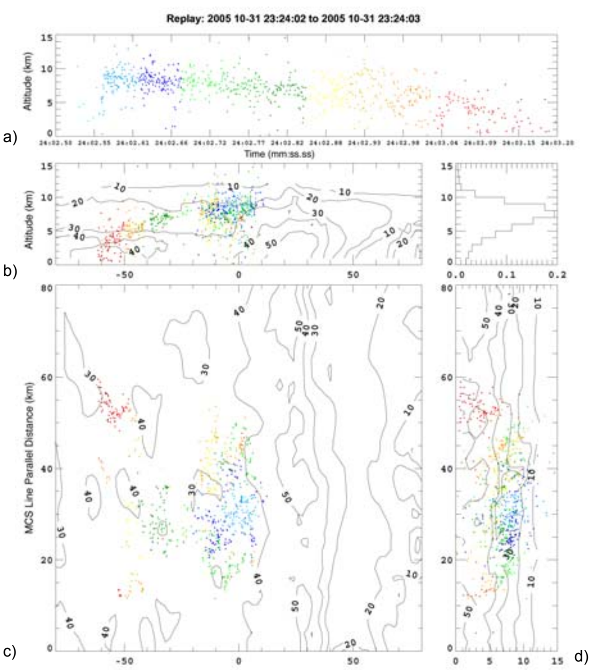

Figure 4. Example of a descending flash detected by the Houston LDAR network plotted on top of the composite radar image during the time period shown in Figure 3.

Initial analyses of the Radar and LDAR characteristics of this storm suggest similar relationships as seen in a study of a Leading-line trailing stratiform (LLTS) mesoscale convective system in Dallas, TX by Carey et al. (2005). Figure 3 is a plot of LDAR lightning source densities overlaid on a composite radar reflectivity for October 31, 2005 at 23:26 UTC. The data was rotated 45° counter-clockwise, compared to Figure 2, to create MCS line normal / line parallel cross sectional plots. The line normal cross section plot (Fig. 3a) clearly shows the maximum LDAR density core above and tilted back away from the most intense convective region. This backwards tilting of the density core suggests a tilted updraft carrying charged particles behind the main convective line. Also evident is the prominent LDAR lightning source 'pathway' that extends rearward and downward from the main LDAR source

Table 1. Approximate values of the individual LDAR sensor detection sensitivities in dBm. Sensor numbers correspond to the sensor numbers found in Figure 1. N/A indicates that the sensor was non-functional during on this day.

LDAR II Sensor Sensitivity on 10/31/2005

Sensor #	1	2	3	4	5	6	7	8	9	10	11	12
Sensitivity	N/A	N/A	-57	-60	-60	-62	-60	-62	-58	-56	-59	-56

density maximum. This pathway travels from the upper part of the main convective region, through the transition zone, and into the radar bright band of the stratiform region. The source density plot also indicates that CG flashes that occur in the stratiform region maybe connected to the observed LDAR lightning source 'pathway'. The planar view of the LDAR source densities (Fig. 3b) shows a similar result to Figure 3a that the LDAR source density maximums occur slightly behind the main convective line. It also clearly shows the horizontal extent, upwards of 75 kilometers, of lightning in the stratiform region.

Figure 4 is a plot of the LDAR source points of an individual lightning flash during the same time period overlaid on the same composite reflectivity as Figures 2 and 3. The time-height plot clearly shows the descending nature of the sample lightning flash. The MCS line normal cross section plot (Fig. 4b) shows the sources from the sample flash follow a similar rearward and downward propagation as seen in the source density plot's LDAR source 'pathway' (Fig. 3a). Also observed in Figures 4b, c and d is the region where the flash originates is displaced above and behind the main convective region similar to the results of the LDAR source density plots during this time period. Plots of several other flashes (not shown) exhibited similar initiation locations and rearward propagation into the stratiform region.

4. NETWORK PERFORMANCE

Since the network became operational in mid July, several noise surveys have been conducted at the various sites in order to improve the networks overall sensitivity to weaker amplitude and/or more distant VHF sources. The first seven sensors were originally tuned to a center frequency near 74 MHz in an attempt to avoid television channels. This produced an average sensor sensitivity of approximately -57 dBm. After continuous monitoring of the sensors, it became clear that the amount of noise during the daytime was much greater than the noise surveys suggested which caused the average sensitivity to be reduced to -55 dBm. In early October, when the nearly constant thunderstorm activity subsided, a new round of noise surveys was conducted for the current ten sensors. From these noise surveys, it was found that tuning the sensors to a frequency between 69 and 71 MHz would improve sensor sensitivity to the values shown in Table 1. Along with the increased sensitivity, came a decrease in the daily fluctuation in noise levels that had been previously observed at several of the sites. It should be noted that the sensors' noise levels are regularly monitored and their gains are adjusted as required and thus sensor sensitivity may vary from day to day.

An important performance feature of the Houston LDAR network that both researchers and average users need is the networks effective range. The squall line discussed in Section 3 was a likely candidate to demonstrate the networks detectable range for several reasons. As the convective line traversed the Houston LDAR coverage area, the intensity of the convective activity remained rather constant and extended well past the anticipated range of the network. In addition, the squall line was traveling through a fairly uniform environment, which suggested the electrical activity of the system would not change drastically during its lifetime.

A plot of source altitudes versus their radial distance gives insight to the networks range. Figure 5 shows a 1 km thick slice of all LDAR sources detected during the 8 hour period when the LDAR network detected any lightning sources that correspond to the squall line. The feature that stands out the most is the fairly dramatic drop off in the number of sources beyond 135 kilometers. This decrease in the number of sources did not appear to correspond with a change in the intensity of the squall line. Also, additional plots (not shown) were made for several other radial directions. In all cases, there

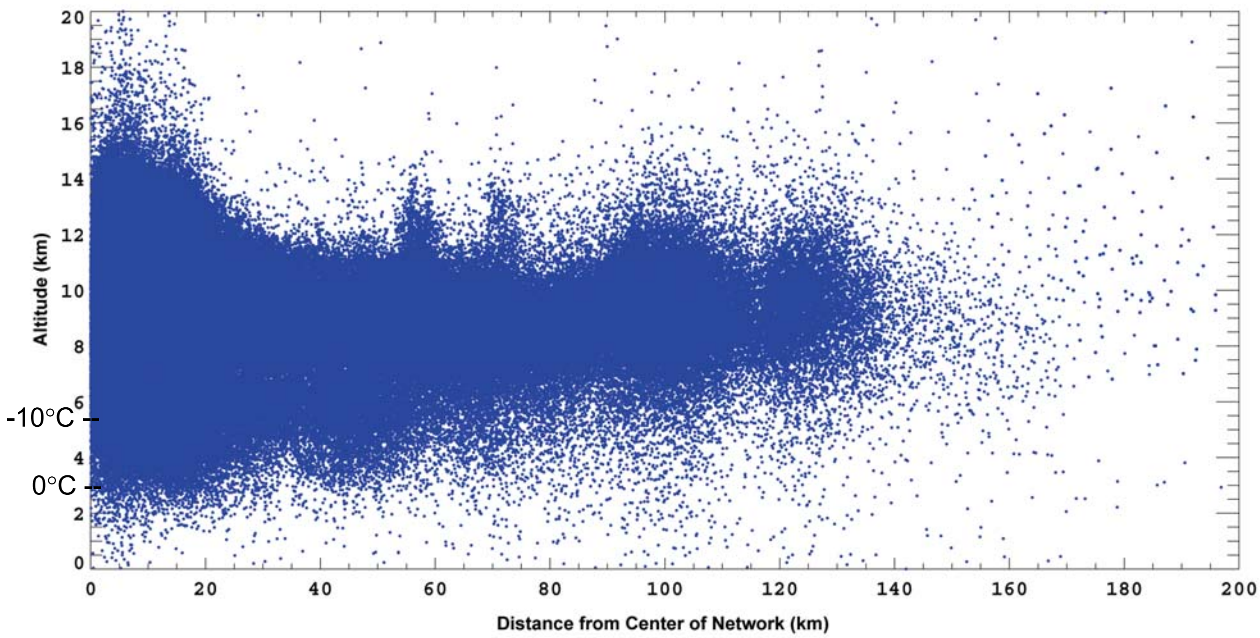

Figure 5. Altitude versus radial distance from the center of the network of sources detected in a 1 km thick slice in a line normal to the squall line propagation and for the time period of 19Z on 10/31/05 to 03Z 11/01/05.

was a significant decrease in the number of sources around 135 kilometers.

The other prominent feature in Figure 5 is the general upward slope of the lower edge of the region of concentrated sources the further the

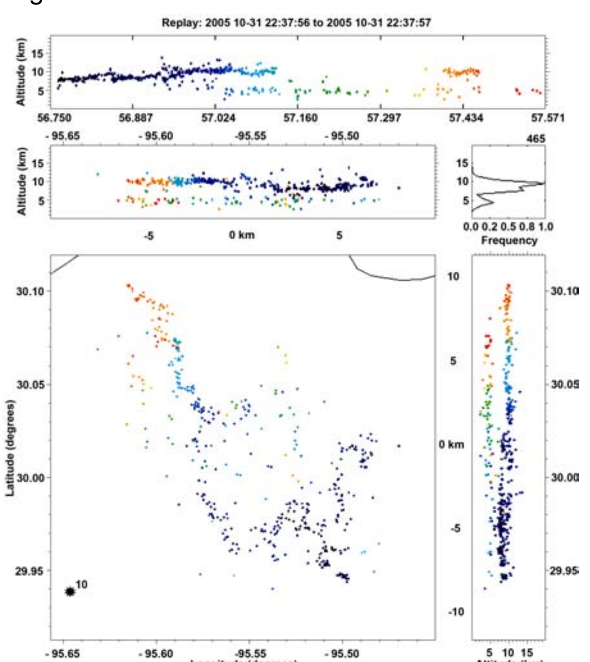

Figure 6. Example of a bi-level lightning flash detected by the Houston LDAR network during the October 31, 2005 squall line. Colors of points denote time from oldest (blue) to newest (red).

storm is from the center of the network. This feature is directly attributable to the line-of-sight propagation of VHF frequencies. Obstructions near the sensor antenna combined with the curvature effect of the Earth cause the sensors to detect less lower elevation lightning sources the further a storm is from the sensors, essentially blocking the sensor sight at low elevation angles. In the case of the October 31st squall line, this means lightning sources in the negative charge layer around 5.5 kilometers are significantly reduced at a range of 100 kilometers.

To verify that the LDAR sources detected by the network seem reasonable, LDAR lightning data that compose an individual flash were plotted. Figure 6 is one such example which depicts an intracloud flash that shows a fairly well defined bi-level structure similar to the structure discussed by Shao and Krehbiel (1996). The intial upward propagation of sources, abundance of VHF activity in the upper branch, and lesser activity in the lower branch suggests the typical dipole charge structure with the positive charge layer on top.

5. DATA DISSEMINATION

One main use of the real-time data produced by the Houston LDAR network is for advanced

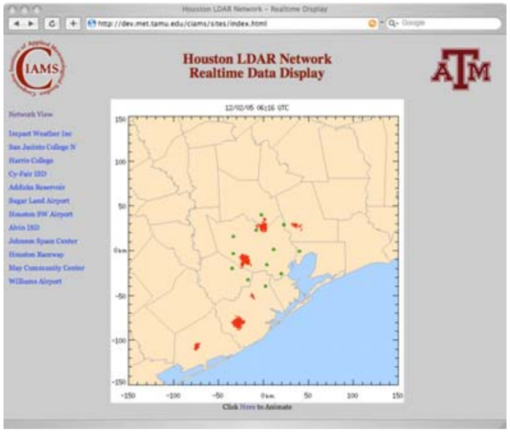

Figure 7. Main page of the Houston LDAR Real-time Display webpage. Green dots indicate LDAR sensor sites which correspond to the list of participating organizations on the left side of the page.

warning of developing thunderstorms in Houston. Organizations that are participating in the operation of the Houston network are able to monitor local lightning activity via a website interface. Plots of the LDAR source data for the last 6 minutes are displayed for each sensor location and the displays are automatically updated every 2 minutes (Figure 7). These images can then be looped to show the change in intensity and direction of motion of the lightning activity.

Future goals are to convert the plots to show the Flash Extent Density (FED), which gives a better representation of the extent of electrical activity. To provide better lightning hazard warning to Houston LDAR cooperating organizations, software will be developed or obtained to send an e-mail and/or voice message to the organizations when lightning is within a pre-defined warning region. This will eliminate the need for the users to continuously monitor the website and instead allow them to perform other tasks until notified of a nearby lightning threat. In addition, Texas A&M, Vaisala, and the NWS offices in League City and Johnson Space Center will work to incorporate the LDAR lightning data into the AWIPS display used by forecasters.

6. CONCLUSIONS

The Houston LDAR II network has been operational since mid-July with at least seven functioning sensors, with ten sensors operational as of mid-August. The operating frequencies of the sensors are in the upper end of TV channel 4 in the 69 to 71 MHz range.

Plots of LDAR source densities overlaid with composite Radar reflectivity reveal a ‘pathway’ that lightning travels from the upper region of the convective core downward and rearward into the stratiform region, following the general wind flow in a squall line. Plots of LDAR sources for individual flashes support the idea that the lightning flashes originate in the convective region and propagate along the path of charged particles into the stratiform region.

After several VHF noise surveys at the sites, the sensors have sensitivity values between -56 to -62 dBm. The maximum range at which lightning source plots do not resemble storm features is approximately 135 kilometers with a dramatic decrease in the number of sources. As was expected, plots of lightning source densities reveal lightning cores that match fairly well with the most intense convective activity. In addition, plots of sources that compose a single intracloud flash reveal a bi-level flash structure similar to observations seen by Rison et al (1999) in central New Mexico.

6. REFERENCES

Carey, L. D., M. J. Murphy, T. L. McCormick, and N. W. S. Demetriades, 2005: Lightning location relative to storm structure in a leading-line, trailing-stratiform mesoscale convective system. *J. Geophys. Res.*, **110**, doi:10.1029/2003JD004371.

Lennon, C., and L. Maier, 1991: Lightning mapping system, *NASA Conf. Publ.*, **3106(2)**, 89.1–89.10.

Orville, R. E., G. Huffines, J. Nielsen-Gammon, R. Zhang, B. Ely, S. Steiger, S. Phillips, S. Allen, W. Read, 2001: Enhancement of cloud-to-ground lightning over Houston, Texas. *Geophys. Res. Lett.*, **28**, 2597-2600, doi:10.1029/2001GL012990.

Rison, W., R. J. Thomas, P. R. Krehbiel, T. Hamlin, and J. Harlin, 1999: A GPS-based three-dimensional lightning mapping system: Initial observations in central New Mexico. *Geophys. Res. Lett.*, **26**, 3573–3576.

Shao, X. M., and P. R. Krehbiel, 1996: The spatial and temporal development of intracloud lightning. *J. Geophys. Res.*, **101**, 26,641–26,668.

Steiger S. M., R. E. Orville, and G. Huffines, 2002: Cloud-to-ground lightning characteristics over

Houston, Texas: 1989–2000. *J. Geophys. Res.*, **107**, doi:10.1029/2001JD001142.

Acknowledgements: We gratefully acknowledge that the scientific research and operation of the Houston network are supported by the National Science Foundation (ATM-0442011 and ATM-0321052). In addition we would like to thank the generosity of the airports, school districts, and colleges around Houston who have donated land, electricity, and internet connections to enable real-time operation of the network.