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The Four Dimensional Lightning Surveillance System

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1. Introduction

The 45th Weather Squadron (45 WS) is the U.S. Air Force unit that provides weather support to America's space program at Cape Canaveral Air Force Station (CCAFS) and National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC). The weather requirements of the space program are very stringent (Harms et al., 1999). In addition, the weather in east central Florida is very complex. This is especially true of summer thunderstorms and associated hazards. Central Florida is 'Lightning Alley', the area of highest lightning activity in the U.S. (Huffines and Orville, 1999). The 45 WS uses a dense network of various weather sensors to meet the operational requirements in this environment (Roeder et al., 2003).

The 45 WS is especially well instrumented with lightning detection sensors. This paper will discuss the Four Dimensional Lightning Surveillance System (4DLSS) in detail. Other lightning systems used by 45 WS include the Launch Pad Lightning Warning System (LPLWS) (Eastern Range Instrumentation Handbook, 2009), a network of 31 surface electric field mills that has a limited total lightning detection capability. The 45 WS also has a direct connection to the National Lightning Detection Network (NLDN) (Orville et al., 2002).

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2. Overview Of The Four Dimensional Lightning Surveillance System (4DLSS)

The 4DLSS implemented two major upgrades. First, the legacy Lightning Detection And Ranging system (LDAR-I) (Boccippio et al., 2001) was upgraded with LDAR-II sensors, and is now called LDAR-II. Second, the sensor observations from the previous Cloud to Ground Surveillance System, hereafter called CGLSS-I, are now processed in the same new LDAR-II processor, and the system is now named CGLSS-II. The 4DLSS began support to space launch at CCAFS/KSC in April 2008.

2.1 LDAR-II Upgrade

The primary reason for 4DLSS was to replace the LDAR-I sensors and processor that had been in use since the early 1990s and were becoming too difficult and costly to maintain. The six LDAR-I sensors were replaced with nine LDAR-II sensors and processed through a CP-8000 processor (Vaisala, 2004). A picture of a LDAR-I and LDAR-II sensor are in Figure-1. A map of the LDAR-II sites is in Figure-2.

Step leaders and other in-cloud lightning mechanisms generate radio pulses. The difference in time of arrival of these radio pulses at pairs of LDAR-II sensors is used to calculate a hyperbolic volume. The intersection of four different hyperbolae locates the step leader in three dimensions (Figure-3). The nine LDAR-II sensors provide many possible locations for a single event. The best location of the step leader is solved via statistical Chi-Squared minimization.

a) Old LDAR-1 sensor.

b) LDAR-II sensor.

Figure 1. Picture of an old LDAR-1 sensor (a) and a new LDAR-II sensor 9(b).

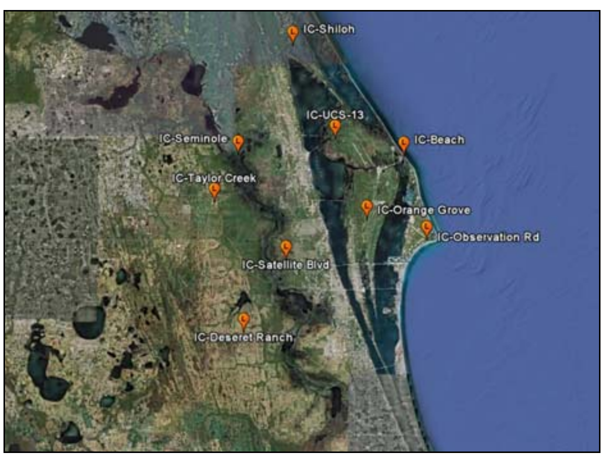


Figure 2. Map of the nine total lightning sensors in LDAR-II.

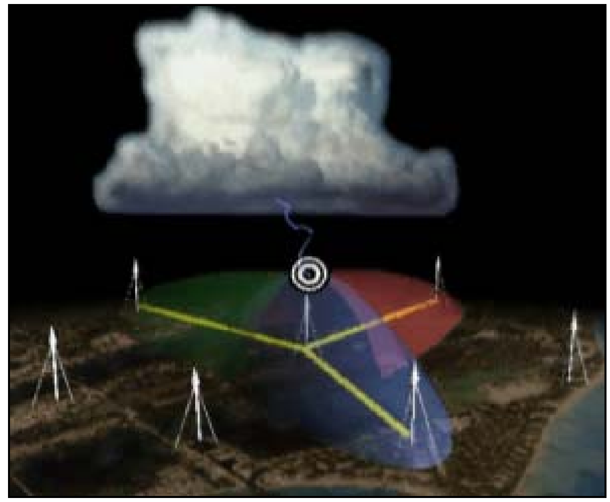


Figure 3. Step leader location via time of arrival differences between pairs of sensors. In general, a step leader location requires four intersecting hyperbolae; although, sometimes only three are needed, as shown here.

2.2 CGLSS-II Upgrade

The 4DLSS also integrated the Cloud to Ground Lightning Surveillance System (CGLSS) sensors (Boyd et al., 2005) into the 4DLSS. The same six sensors from CGLSS-I are still used (Figure-4). However, the data are processed through the new CP-8000 processor used in LDAR-II. This allows solving for all return strokes in real-time; CGLSS-I could only solve for one stroke per flash in real-time. As a result, CGLSS-II detections increased to ~250% of CGLSS-I. Given the frequency of lightning flashes with multiple ground strike locations and the large distance between these strokes, detecting all strokes yielded a considerable improvement in 45 WS lightning reports (Flinn et al. 2010a; 2010b) and lightning advisories (Weems et al., 2001). The return strokes are located via magnetic direction finding and time of arrival (Figure-5). Two or more sensors are required for magnetic-direction-finding locations. Three or more pairs of sensors are required for time-of-arrival locations. The six sensors provide multiple solutions per return stroke and the optimal location is calculated via statistical Chi-Squared minimization. A map of the CGLSS-II sensors is in Figure-6.

Figure 4. Picture of the sensor used in both the previous CGLSS-I and current CGLSS-II.

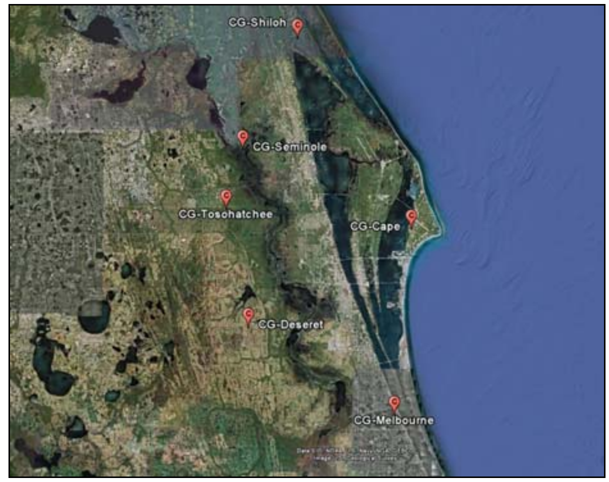
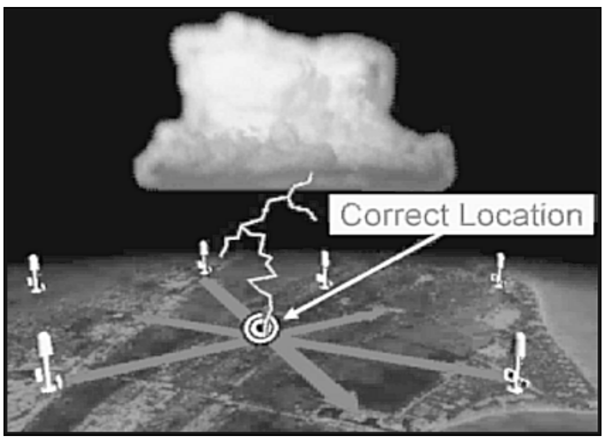
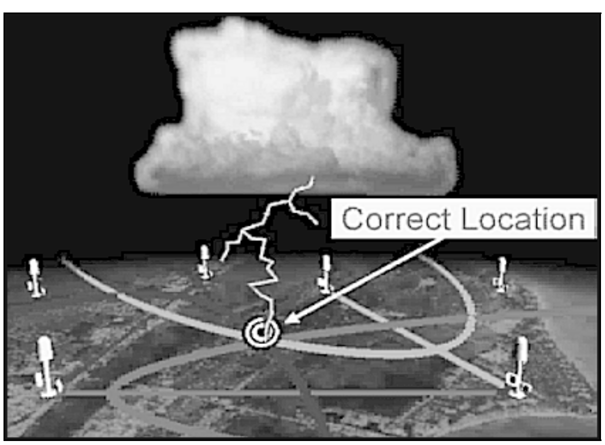


Figure 6. Map of the six cloud to ground lightning sensors in CGLSS-II.



a) Return stroke location via magnetic direction finding.



b) Return stroke location via time of arrival.

Figure 5. Return strokes are located by magnetic direction finding (a) and time of arrival 9(b).

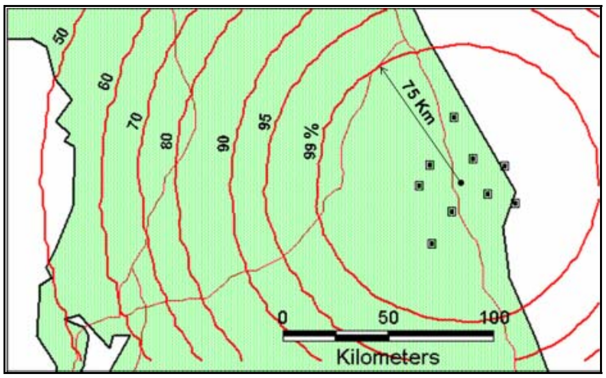
3. Performance Of 4DLSS

The 4DLSS matched or exceeded the performance of the legacy LDAR-1 and CGLSS-I systems. The performance of 4DLSS in the center of the network is summarized in Table-1. The performance of LDAR-II throughout east central Florida is shown in Figure-7. The performance of CGLSS-II throughout east central Florida is shown in Figure-8. Further details of the 4DLSS performance are in Murphy et al. (2008). These performance metrics assumed that all of the sensors were used in the lightning solutions. However, even in the center of the network, this is not always true for CGLSS-II, which has a median of 4.80 sensors per solution (Figure-9). The 45 WS began providing location error ellipses for cloud-to-lightning in Spring 2009 (Flinn et al., 2010a; 2010b). The mean area of return stroke location error ellipse error was 0.349 km^2 for 4,770 strokes near the launch pads during 1 Apr-25 Jul 09. This suggests a median location accuracy of 333 m, as compared to the best-case performance of 250 m in Table-1. The difference in performance is due primarily to all six sensors not being used in all the lightning solutions.

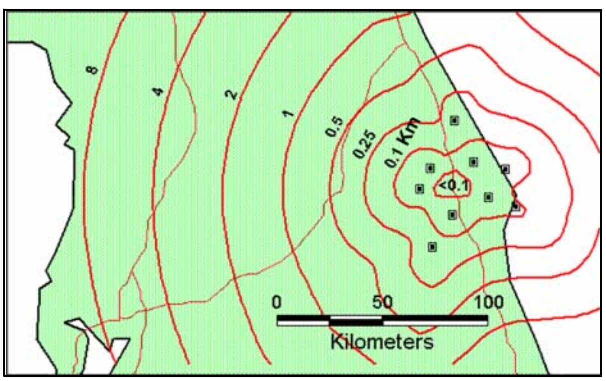
Table-1
Performance of the 4DLSS.

Intra-Cloud Component of 4DLSS (aka LDAR-II)	
Detection Rate (flash) *	100%
Location Accuracy (median) *	100 m
Detections vs. LDAR-I	140%
Cloud-to-Ground Component of 4DLSS (aka CGLSS-II)	
Detection Rate (return stroke) *	98%
Location Accuracy (median) *	250 m
Detections vs. CGLSS-I	250%

* In center of the network. Assumes all sensors are used in the lightning solution.

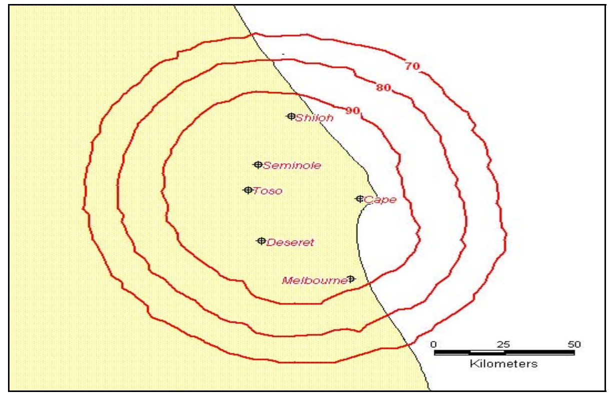


a) LDAR-II detection rate

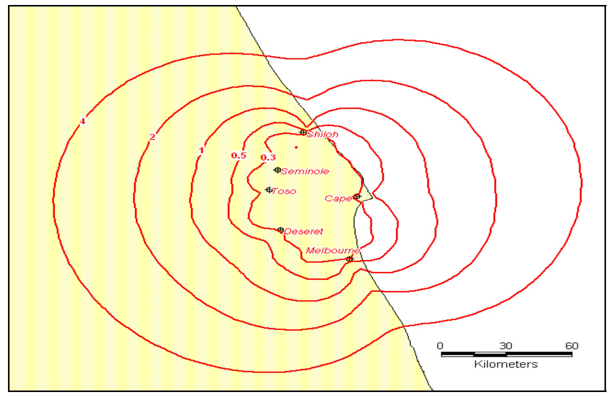


b) LDAR-II location accuracy (50% confidence)

Figure 7. Performance of LDAR-II across east central Florida, detection rate (a) and location accuracy (b), assuming all nine sensors are used in the solution (figures from Murphy et al., 2008).



a) CGLSS-II detection rate



b) CGLSS-II location accuracy (50% confidence)

Figure 8. Performance of CGLSS-II across east central Florida, detection rate (a) and location accuracy (b), assuming all six sensors are used in the solution. Results are from the Vaisala performance model.

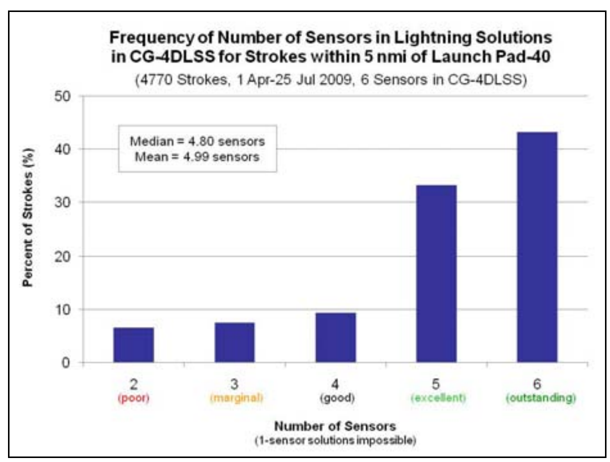


Figure 9. Distribution of number of sensors used in location solutions by CGLSS-II for strokes inside the network.

3.1 Additional LDAR-II Benefits

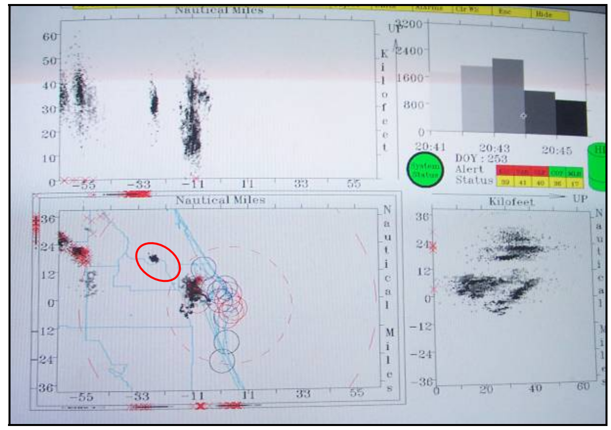
The LDAR-II provides several benefits over the previous LDAR-I. For example, 'radial smearing' has been significantly reduced (Figure-10). In LDAR-I, radial location error increased much faster with range than the azimuthal error. As a result, the location of lightning storms would appear to be smeared along lines radial to the network. This could lead to false lightning warnings for CCAFS/KSC as lightning from nearby thunderstorms 'smears' over the warning areas. The reduction of radial smearing is due to the LDAR-II network being about 2.5x wider than LDAR-I.

Another benefit of LDAR-II is that is shows finer lightning structures than LDAR-I (Figure-11). This is due to the reduced radial smearing, combined with the increased detection rate. In addition, LDAR-II occasionally showed small new thunderstorm cells before LDAR-I (Figure-12). This may an example of improved detection, or it may be due to the system clocks of both systems not being synchronized, i.e. LDAR-I might show the new cells in the next 1-minute screen refresh.

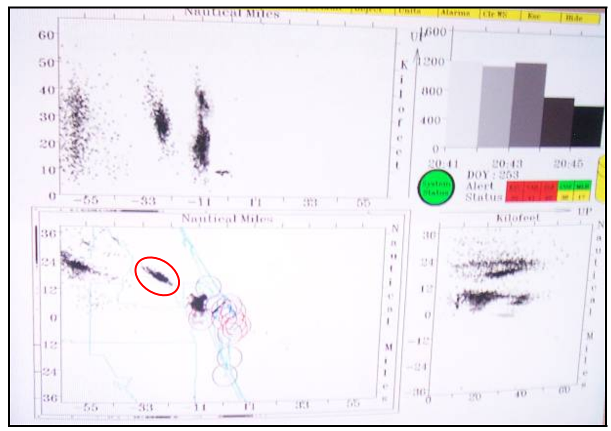
Finally, LDAR-II eliminated signals from aircraft (Figure-13). LDAR-I would occasionally detect and display static discharges from aircraft flying through precipitation. This problem was eliminated as a fortuitous consequence of the larger distances between the sensors. One of the quality control requirements of LDAR-II is that the signal must be above a threshold at five or more of the nine sensors before a lightning solution is calculated. Since the static discharge from aircraft flying in precipitation is much weaker than natural lightning, the signal falls below the quality control threshold before it reaches five sensors.

3.2 Additional CGLSS-II Benefits

CGLSS-I had a minor shortfall of reporting lightning well outside the CCAFS/KSC as being closer than its true location. This problem was fixed under CGLSS-II. Figure-14 shows an example of this improvement.

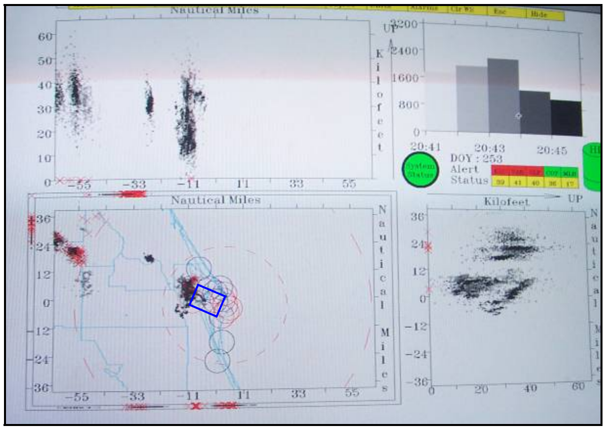


a) LDAR-II display of lightning data for the same date, time, and area. The red Xs are cloud-to-ground strikes from CGLSS-II.

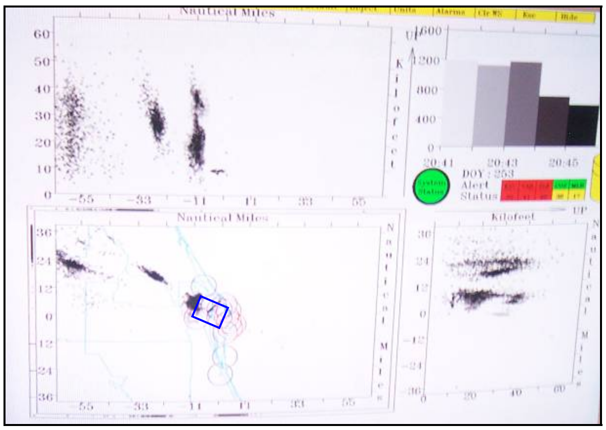


b) LDAR-I display of lightning data for the same date, time, and area. The cloud-to-ground strikes (red Xs) are not shown.

Figure-10. LDAR-II significantly reduced the 'radial smearing' in LDAR, as highlighted by the red ovals.

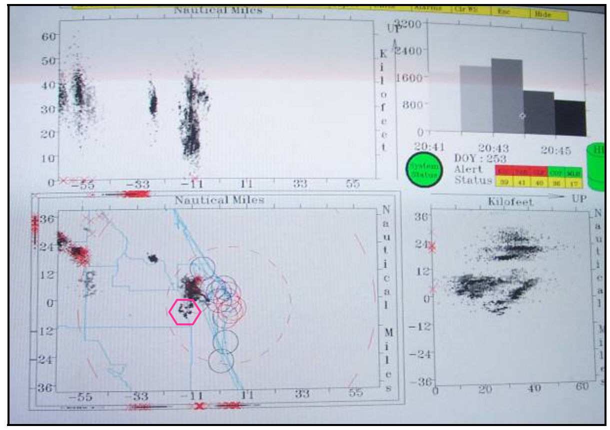


a) LDAR-II display of lightning data for the same date, time, and area. The red Xs are cloud-to-ground strikes from CGLSS-II.

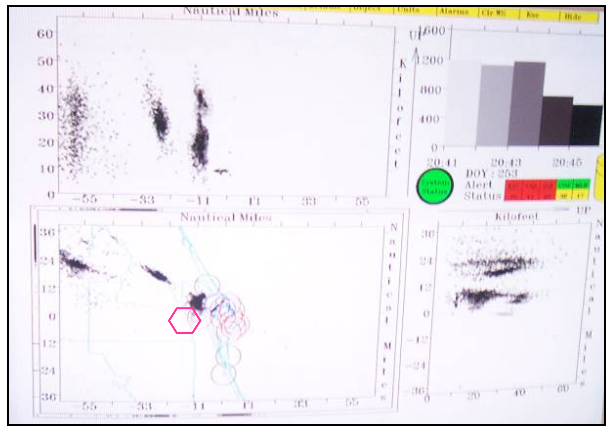


b) LDAR-I display of lightning data for the same date, time, and area. The cloud-to-ground strikes (red Xs) are not shown.

Figure-11. LDAR-II showed much finer lightning structures than LDAR, as highlighted by the blue rectangles.

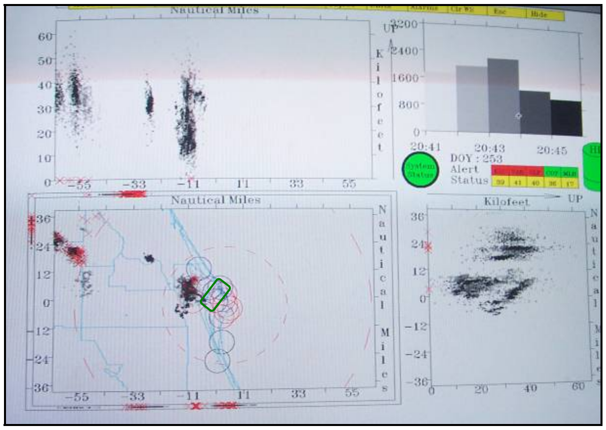


a) LDAR-II display of lightning data for the same date, time, and area. The red Xs are cloud-to-ground strikes from CGLSS-II.

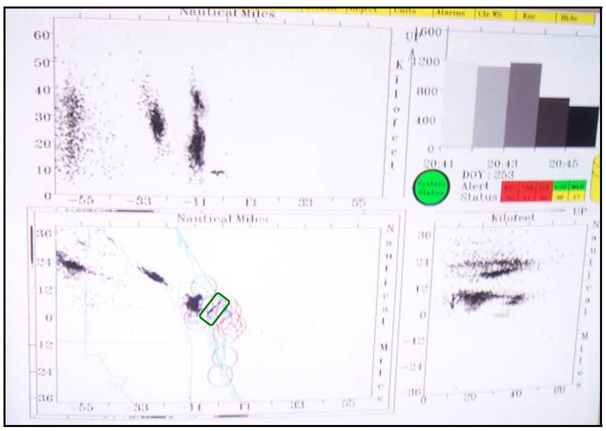


b) LDAR-I display of lightning data for the same date, time, and area. The cloud-to-ground strikes (red Xs) are not shown.

Figure-12. LDAR-II sometimes showed small new thunderstorm cells not displayed by LDAR-I, as highlighted by the magenta hexagons. This may be a result of the increased detection rate or it may be due to the system clocks not being synchronized exactly, i.e. the new cells may be in LDAR-I on the next 1-minute refresh.



a) LDAR-II display of lightning data for the same date, time, and area. The red Xs are cloud-to-ground strikes from CGLSS-II.

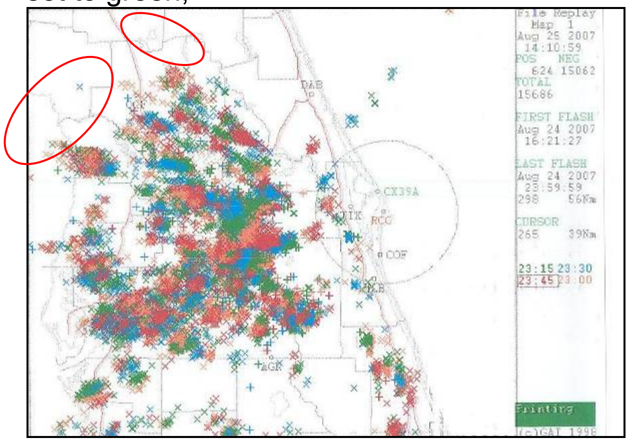


b) LDAR-I display of lightning data for the same date, time, and area. The cloud-to-ground strikes (red Xs) are not shown.

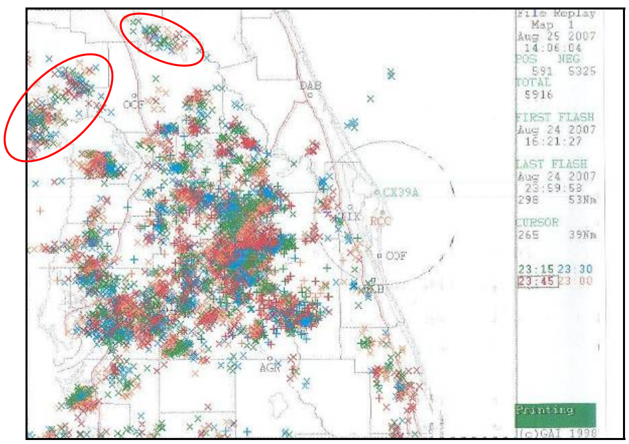
Figure-13. LDAR-II eliminated the signals from aircraft LDAR-I frequently depicted, as highlighted by the green rounded rectangles.

3.3 Improved LDAR-II System Status

The LDAR-II provides a simple system status display for quick reference by forecasters. This system status is a colored circle where green corresponds to nominal system performance, yellow is marginal, and red is poor performance or broken. The system status is set based on the number of operating sensors. The system status versus number of sensors operating is in Table-2. The previous LDAR-I used a similar approach, except that if 25 or more step leaders were detected, the system status was set to green,



a) CGLSS-II display of lightning data from the same date, time, and area.



b) CGLSS-I display of lightning data from the same date, time, and area.

Figure-14. CGLSS-II corrected the problem of CGLSS-I reporting lightning far outside the KSC/CCAFS area as radially closer than its real location, as highlighted by the red rectangles.

regardless of the number of sensors operating. That leads to potential problems with the wider spaced sensors in LDAR-II. For example, a single lightning flash near the edge of the network could easily generate 25 or more detections from four sensors nearest that edge of the LDAR-II network. That would set the system status to green even when 5 sensors are not operating and the system status should be red. As a result, the resetting of system status based on number of detections was deactivated in LDAR-II.

Table-2
LDAR-II system status display based on number of sensors operating. Green means good-to-acceptable performance, yellow means marginal performance, and red means unacceptable performance or system broken.

System Status	Number of Sensors Operating
Green	9
Green	8
Yellow	7
Red	6
Red	5
Red	4
Red	3
Red	2
Red	1
Red	0

4. On-going Improvements To 4DLSS

4.1 CGLSS-II On-going Improvements

Recent research has shown that CGLSS-II can be saturated by strong local strokes and fail to detect them, especially those with peak currents of 50 KA or greater (Ward et al., 2008). However, CGLSS-II excels at detecting weak local strokes. On the other hand, the wider spacing of the NLDN sensors excels at detecting strong strokes, but loses detection efficiency for weaker strokes near CCAFS/KSC, especially those with peak currents of 7 KA or less. This suggests that combining the sensor data from both systems in real-time could lead to improved performance. The 45 WS is pursuing integrating data from nine NLDN sensors into CGLSS-II in real-time to improve the detection of strong local strokes. The nine NLDN sensors being considered are based on those closest to CCAFS/KSC and those with the best complementary geometry relative to CCAFS/KSC: all seven in FL, one just across the state line in GA, and one in the Bahamas Islands. Incorporation of the sensor data from those NLDN sensors into CGLSS-II in real-time will also improve the location accuracy, detection efficiency, and provide smaller and less eccentric error ellipses when only a few of the CGLSS-II sensors are used in the solution. The performance of CGLSS-II will not be compromised when most of the CGLSS-II sensors are used in the lightning solution.

As an interim measure, KSC is purchasing StrikeNet reports (Vaisala, 2006) from Vaisala, Inc. when lightning strokes are detected or suspected near KSC points of interest. The StrikeNet reports include all the strokes detected by NLDN, not just flash-only data, and as a result should include the strong local strokes missed by CGLSS-II. The StrikeNet reports also allow cross-comparison with the CGLSS-II to check for consistency in lightning locations and peak current. The StrikeNet solution is not as good as integrating the nearby NLDN sensors into CGLSS-II since the stroke location, error ellipses, and peak current solutions are not optimized with all the sensor data from both systems. In addition, inconsistencies between the two reports may occur, requiring manual analysis to reconcile. However, the StrikeNet reports are available now, while the integration of the NLDN sensors into CGLSS-II is still being developed. The 45 WS may acquire StrikeNet reports to support their DoD, NASA unmanned, and commercial launch customers.

4.2 LDAR-II On-going Improvements

No improvements to LDAR-II are in progress at this time (Feb 2010).

5. Possible Future Improvements To 4DLSS

Both the CGLSS-II and LDAR-II components of 4DLSS require future improvements. None of the projects are planned or funded at this time.

5.1 CGLSS-II Future Improvements

The CGLSS-II requires future improvement in three major areas: 1) peak current, 2) peak current error, and 3) system upgrades.

5.1.1 Improved Peak Current

At present, the peak current estimate is calculated from the peak magnetic field at each sensor. The peak magnetic field is normalized to a range of 100 km and corrected for attenuation from ground propagation effects. The mean of the attenuation-corrected, range-normalized peak magnetic fields is converted to peak current via a regression equation (Cummins et al., 1998). That regression equation was based primarily on data from rocket-triggered lightning. As a result, it is less representative for first strokes from natural lightning. This is important to operations since the first stroke in a flash tends to have the highest peak current. Thus, the first stroke can generally cause more induced current damage at the same distance or the same induced current damage at farther distances than subsequent return strokes.

Perhaps the best way to improve peak current estimates is to create a new regression equation based on observations of natural lightning. Unfortunately, there have been few direct peak current measurements of natural lightning. An appropriately instrumented tall tower in a wide open flat area with frequent lightning and subsequent analysis of that data should allow significantly improved peak current estimates, especially for the operationally more important first strokes. The CCAFS/KSC has a network of weather towers that would be a natural candidate for such an instrumented tower given the lightning frequency and terrain in that area. An analysis of tower height versus climatological flash density, along with surrounding terrain and logistical accessibility, should be conducted to identify the best tower to be instrumented. For example, Tower-313 is the tallest tower in the network (500 ft) but is located ~3 nmi from the coast. Shorter towers farther inland might be more likely to be struck by lightning since the climatological lightning flash density increases inland. Funding for this project was not available at the time this paper was written (Feb 2010).

There may be ways to improve the range-normalized, attenuation-corrected regression equation approach used at present. For example, using an average peak magnetic field weighted by distance to the stroke for each sensor, rather than a simple mean, may yield some performance improvement. Sensors farther from the stroke would receive less weight in the distance weighted average.

Another possible improvement could be separate regression equations based on stroke polarity. Likewise, different regression equations for varying peak current should also be considered, e.g. perhaps an iterative process where the regression coefficients are modified based on the peak current from the previous iteration, or a simpler approach of stratified regression equations for weak, moderate, and strong peak current.

Finally, entirely new approaches should be explored to avoid the additional uncertainties introduced by the range-normalization and the regression equation.

5.1.2 Improved Peak Current Error

The estimated error associated with the peak current estimates for cloud to ground lightning strokes from CGLSS-II has not been as well studied as location accuracy and detection rate, especially for various combinations of sensors used in the solution for each stroke. At present, a single error estimate of ±20% is used for all strokes, regardless of number of sensors used in the solution and distance of those sensors to the lightning stroke. This is the vendor's recommendation and is based on the performance of the NLDN, which itself appears to be based on some old studies of relatively small sample size. It appears that most customers are more interested in detection rate and location accuracy than in peak current accuracy. Some lightning detection experts have suggested that the actual errors in peak current are larger than ±20% (Mata, 2009).

The 45 WS is interested in improved error estimates for peak current provided by CGLSS-II. One possible approach might be using the variability of the peak current estimated from each sensor for a better measure of the peak current error. This could also allow a statistical estimate of the confidence intervals and/or a high percentile, e.g. inter-quartile range, 95th or 99th percentile. A best-fit Gaussian distribution might also be applied. The standard deviation of the best-fit Gaussian distribution could be used to generate confidence intervals. The space launch customers could then factor the uncertainty of peak current more effectively into decisions to inspect mission essential electronics, just as done now with location accuracy, i.e. determine the probability of exceeding their combined thresholds of distance and peak current.

5.1.3 CGLSS-II System Upgrades

The 45 WS is interested in upgrading the CGLSS-II system. Four main possible approaches to upgrade CGLSS-II are available. First, conduct a new Network Performance Evaluation Program (NPEP) and schedule them periodically. Second, replace the CGLSS-II sensors with the new model for long-term maintenance sustainability. Third, integrate any new nearby NLDN sensors into CGLSS-II. Fourth, add a new seventh sensor to CGLSS-II. Unfortunately, none of these activities is currently funded.

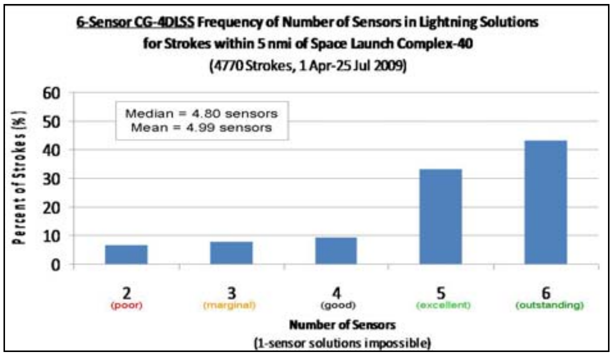
5.1.3.1 New And Periodic Network Performance Evaluation Program

A Network Performance Evaluation Program (NPEP) was last done on 4DLSS in the summer of 2008, shortly after the system was installed. No major problems were found, but a minor radio noise problem was detected at one of the sites. A new NPEP should be conducted, since one is recommended every 1.5 years. If the previous minor radio noise problem still exists, a remediation may be worthwhile. Also the NPEP would check for any new problems. The NPEP should be repeated every 1.5 years for stable lightning detection systems that are performing well, as recommended by the vendor (Vaisala, 2008).

5.1.3.2 Replace CGLSS-II Sensors

The current CG-lightning IMPACT Model 141-T sensors are no longer supported by Vaisala, Inc. This is already causing maintenance problems. The Melbourne sensor was damaged by a lightning strike on 26 Jul 09 and a replacement sensor was not available, so CGLSS-II is in a temporary 5-sensor configuration at this time (Feb 10), rather than the nominal 6-sensors. The Tosohatchee sensor was moved to the Melbourne site to replace the sole line of sight to CCAFS/KSC from the south (see Figure-6). The line of sight from the west provided by Tosohatchee is duplicated by the Seminole sensor. Fortunately, Vaisala is currently manufacturing the LS7001 sensor (Vaisala, 2009), which they will support for many years. This new sensor should be a simple plug-in replacement of the current sensor with no loss of performance and requiring no other changes. A test of the new sensor in CGLSS-II is in progress. The replacement of all the current sensors is not yet funded, pending results of the test.

The testing of the new LS7001 sensor, and subsequent replacement of the current CGLSS-II sensors, may be taking on heightened urgency. Preliminary analysis indicates that the performance loss to cloud-to-ground lightning detection was larger than expected after the loss of the Melbourne sensor on 26 Jul 09 and relocation of the Tosohatchee sensor to the Melbourne site on 11 Aug 09 (see Figure-6 for site locations). The Tosohatchee sensor was relocated to replace the sole line-of-sight from the south to CCAFS/KSC. The frequency distributions of number of sensors per lightning solution are in Figure-15. Some other performance indicators are listed in Table-3. The performance of the temporary 5-sensor configuration fell much more than expected. A possible cause of this unexpectedly large drop in performance was uncovered and a corrective fix done on 18 Feb 10. We are now waiting for local real-world lightning to verify that the fix worked and document the new performance numbers.



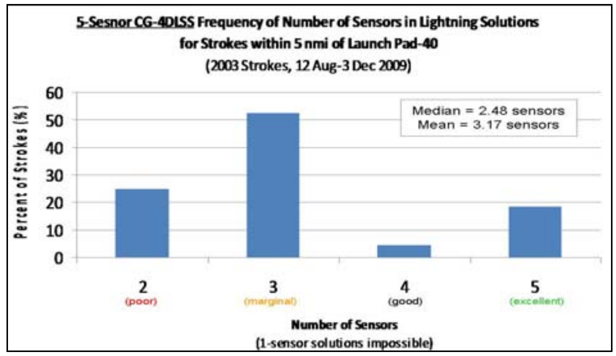


Figure 15. Frequency of number of sensors per lightning solution for strokes near the CCAFS/KSC launch pads under the nominal 6-sensor configuration and the current temporary 5-sensor configuration.

Table-3

Some performance indicators for the nominal 6-sensor configuration of CGLSS-II and the current temporary 5-sensor configuration.

	6-Sensor Configuration	5-Sensor Configuration
Median Number of Sensors per Lightning Solution	4.80 *(nearly excellent performance)*	2.58 *(just below marginal performance)*
Percentage of Solutions With ≤ 3 Sensors	14.1% *(marginal or poor performance)*	69.9% *(marginal or poor performance)*
Median Area of Error Ellipses	0.349 km^2	0.699 km^2
50% Confidence Radius of Circle Equal in Area to Median Error Ellipse	333 m	472 m
95% Confidence Radius of Circle Equal in Area to Median Error Ellipse	693 m	981 m
99% Confidence Radius of Circle Equal in Area to Median Error Ellipse	860 m	1,216 m
Median Eccentricity of Error Ellipses	0.866	0.917

5.1.3.3 Integrate Any New Nearby NLDN Sensors

The on-going effort to ingest data from nine surrounding NLDN sensor data to 4DLSS was discussed in section-3. When that effort began in early 2009, Vaisala, Inc. was considering adding another NLDN sensor in central Florida, perhaps near Daytona Beach. If that sensor is added to NLDN, then it should also be incorporated into CGLSS-II. Likewise, any other new NLDN sensors added within ~300 nmi of CCAFS/KSC should be considered for integration into CGLSS-II.

If the new NLDN sensor is not added, the 45 WS may consider adding a new eighth 4DLSS sensor to CGLSS-II at a distance of about 60 nmi from KSC/CCAFS. This new eighth sensor would be in addition to the new seventh sensor discussed in section 5.3.4. However, it may be more cost-effective to cost-share a new NLDN at that location and ingest its data into CGLSS-II. Either approach should help reduce the problem of strong local strokes sometimes not being detected by CGLSS-II.

5.1.3.4 Add A New Seventh Sensor To CGLSS-II

The performance of CGLSS-II could be made more robust if a new seventh sensor was added. If this new seventh sensor is sited at a near center location, it should reduce the sensitivity to performance if the Cape sensor is not used in the solution. In addition, the preliminary analysis of performance loss under the current temporary 5-sensor configuration suggests the gain in robustness with a new seventh sensor may be worthwhile. If this new seventh sensor is added, a location at the southwest edge of KSC should provide increased performance for lightning near the launch pads if the Cape sensor is used in the solution. If this new seventh sensor is added, moving the Seminole sensor a few miles to the northeast would optimize the performance of CGLSS-II slightly, but this change may not be cost-effective. The addition of a new seventh sensor has not yet been formally recommended by 45 WS yet so funding has not been considered.

5.2 LDAR-II Future Improvements

The LDAR-II requires improvement in two major areas: 1) system sustainability, and 2) system upgrades.

5.2.1 System Sustainability

The LDAR-II sensors are no longer being supported by Vaisala, Inc. Future maintenance will become increasing difficult as spare parts are consumed. Eventually, LDAR-II system performance will degrade and eventually fail, degrading future support to weather support to CCAFS/KSC. The 45 WS hopes to purchase the sensors from other LDAR-II networks if they are discontinued. Another option is to acquire a large number of LDAR-II sensors as a one-time purchase to stockpile spares for use several years into the future.

5.2.2 System Upgrades

Three system upgrades are desired to LDAR-II: 1) additional sensors, 2) upgraded display workstation, and 3) reduced noise.

5.2.2.1 Additional LDAR-II Sensors

Adding one to four additional sensors to LDAR-II would be beneficial. A new seventh sensor extending the network southward would help improve coverage to south for lightning warnings at PAFB and Joint Stars at Melbourne airport. This would also improve system robustness to sensors not working or not used in lightning solutions. Patrick AFB may not be the optimal location, but it is close and practical concerns such as not leasing private land, and access to power and communications suggest that Patrick AFB would be a good choice for a new seventh sensor. A new eighth sensor would be useful to extend best location accuracy, and to a much lesser degree, detection rate from the center of the network (just west of CCAFS/KSC (see Figure-7b)) to over CCAFS/KSC, especially to over the launch pads. This will also increase robustness of performance over the CCAFS/KSC area, and to a lesser degree across the east central Florida, to out-of-service sensors or sensors not used in the lightning solution. A location between the two easternmost sensors in the current network would be a likely location for this new sensor. A new ninth or ninth and tenth sensor would be useful to extend detection rate westward, and to a lesser degree location accuracy, for Lightning LCC evaluation, especially for anvil clouds. The Lightning LCC are the weather rules to avoid rocket triggered and natural lightning to in-flight rockets (McNamara et al., 2010). This will also increase overall performance to out-of-service sensors or sensors not used in the lightning solution. The locations for these ninth and tenth sensors would be relatively far to the west of the current westernmost sensors of the current network.

5.2.2.2 Upgraded LDAR-II Display Workstation

The same display workstation used by the original LDAR-I is still in use because it was not upgraded under 4DLSS to save cost. Unfortunately, the increased detection rate of LDAR-II exceeds the throughput of the display workstation. While displayed detection rate of LDAR-II increased to ~140% of LDAR-I, some detections are not being displayed. A faster display workstation with more memory should increase LDAR-II displayed detections even further. The display software for LDAR-II is the same used for LDAR-I and was written for a DEC computer, so an upgraded workstation must be DEC compatible. The 45 WS submitted a request for an upgraded display workstation and monitor for LDAR-II.

5.2.2.3 Reduced LDAR-II Noise

LDAR-II occasionally displays random noise, presumably from radio interference. Figure-16 shows a strong example of this noise with a few hundred false solutions per minute. A more typical noise rate is a few tens of false solutions per minute or less. This noise occurs under strong nocturnal inversions after strong cold front passages in winter. The 45 WS considers this a minor irritation to operations since is easily identified by three conditions: 1) random 3-D distribution and persistence over time, which is very unlike lightning flashes, 2) the weather conditions and timing, which coincides when lightning is not expected, and 3) the lack of other lightning signatures on the other lightning detectors used by 45 WS and the lack of deep convection on radar. Indeed, except for perhaps some shallow stratus or stratocumulus clouds, there are usually no clouds in the area at these times, and certainly no deep convective clouds. This problem appears to be radio interference caused by low-level ducting by the nocturnal inversion. The obvious solution is to decrease the sensitivity of the LDAR-II sensors. Unfortunately, this might decrease the detection rate for real lightning, which is counterproductive. A radio interference survey under these weather conditions might allow identification of a specific wavelength causing the interference and allowing a notch filter. A decrease of the frequency and intensity of the noise was noticed in the winter of 2008-2009 as compared to the winter of 2007-2008, which may have been due to the national conversion of television from analog to digital broadcasts. However, an increase was noticed in winter 2009-2010, presumably due to more strong nocturnal inversions than average.

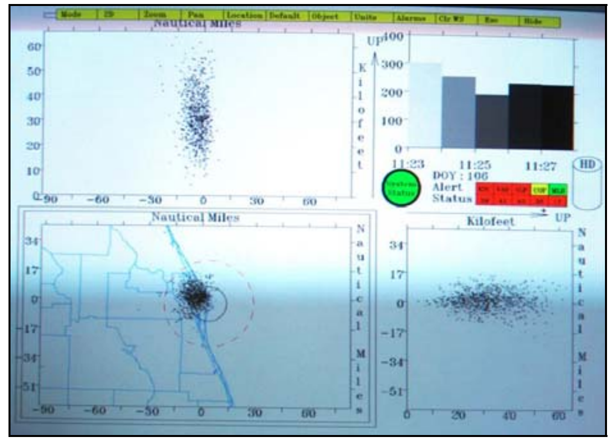


Figure 16. An example of strong noise occasionally displayed by LDAR-II on mornings with strong nocturnal inversions.

6. Summary

The Four Dimensional Lightning Surveillance System (4DLSS) upgraded the previous 6-sensor LDAR-I total lightning detection system with a 9-sensor LDAR-II network with ~2.5 times larger spacing between sensors. This led to performance that exceeded or matched the old LDAR-I system. In particular, the new 4DLSS has 140% of the detections of LDAR-I and has greatly reduced the 'radial smearing' of LDAR-I. Since the radial and azimuthal errors with range have changed significantly from LDAR-I, researchers will need to create a new error model and flash algorithm before compressing the extremely voluminous intra-cloud lightning detections into flashes.

The 4DLSS upgrade also integrated the previous six CGLSS-I sensors and processed those data with the 4DLSS processor. This allowed detection and reporting of all return strokes in real-time resulting in 250% of the detections of CGLSS-I.

Other improvements from 4DLSS were discussed.

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