# 8.5 APPLICATIONS OF THE CLOUD-TO-GROUND LIGHTNING SURVEILLANCE SYSTEM DATABASE

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## 1. INTRODUCTION

The 45th Weather Squadron (45 WS) provides comprehensive weather services to America's space program at Cape Canaveral Air Force Station (CCAFS) and NASA Kennedy Space Center (KSC) (Harms et al., 1999). Since these facilities are in central Florida, 'lightning alley' of North America, lightning is the one of the most important parts of this weather support. The 45 WS lightning support is summarized in Table-1. To help provide this weather support, the 45 WS uses one of the most extensive suites of lightning detectors in operational meteorology (Harms et al., 2003). This suite of lightning detectors is summarized in Table-2. Part of this suite is the Cloud-to-Ground Lightning Surveillance System (CGLSS). The CGLSS is a high-performance local cloud-to-ground lightning detector that consists of six Improved Accuracy via Combined Technology sensors (Cummins et al., 1998) similar to those used in the National Lightning Detection Network (NLDN) (Cummins et al., 1999). The six sensors are spaced much closer than in the NLDN and are maintained and calibrated extremely well, all of which contributes to the excellent detection efficiency and location accuracy of CGLSS in the local area and especially within its network. The locations of the CGLSS sensors are in Figure 1. A more complete description of CGLSS is at Boyd et al. (2005).

**Table 1.**
45 WS lightning support.

| ACTIVITY | PURPOSE | REFERENCE |
|---|---|---|
| Evaluate and forecast Lightning Launch Commit Criteria | Prevent natural and rocket triggered lightning strikes to in-flight rockets | Roeder et al., 1999 |
| Routine 24/7 lightning advisories | Personnel safety and resource protection | Weems et al., 2001 |
| Daily lightning observation report | Evaluate electromagnetic pulse damage to payloads and rockets | N/A |
| Special lightning forecasts for pre-launch ground process operations | Personnel safety and resource protection | Roeder and Pinder, 1998 |
| Lightning probability forecasts for daily 24-hour and Weekly planning forecasts | Mission planning | N/A |
| Non-routine lightning observations | Climatological studies, Equipment validation, Post fire analysis, Labor analysis/scheduling | N/A |
| Lightning safety education | Personnel safety | Roeder et al., 2004 |

**Table 2.**
45 WS lightning sensors.

| SENSOR | TYPE DETECTED | PART DETECTED | DETECTION TECHNIQUE | DETECT. RATE | LOCATION ACCURACY |
|---|---|---|---|---|---|
| Lightning Detection And Ranging (LDAR) | All Lightning | Step Leader | Time Of Arrival | ~100% | 100 m |
| Cloud-to-Ground Lightning Surveillance System (CGLSS) | Cloud-To-Ground Lightning | Return Stroke | Time Of Arrival and Direction Finding | 98% | 300 m (50% conf.) 350 m (95%) |
| Launch Pad Lightning Warning System (LPLWS) | All Lightning | Surface Electric Field | Center Of Electric Charge Change | ~90% | 2 Km to 1/2 Lightning Length (vertical to horizontal lightning) |
| National Lightning Detection Network (NLDN) | Cloud-To-Ground Lightning | Return Stroke | Time Of Arrival and Direction Finding | 95% | 500 m (50% conf.) |

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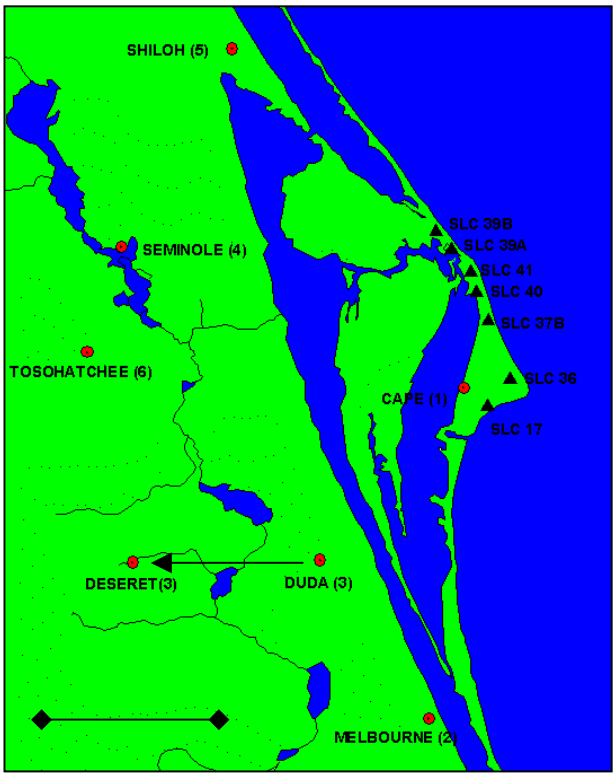


**Figure 1**. Location of the six CGLSS sensors. The #3 sensor was moved from Duda to Deseret in 2004 due to loss of lease and for improved redundancy in east-west look angle.

## 2. REAL-TIME USES OF CGLSS

The primary use of CGLSS in daily operations is to evaluate the electromagnetic pulse impact of nearby lightning strikes on sensitive electronics in payloads and launch vehicles. This is done via a daily report of the past 24-hours of nearby CGLSS observations using the on-line saved data. Depending on the proximity and intensity of the cloud-to-ground flash, various levels of testing are required for the electronics.

Another daily use of CGLSS is forecasting lightning via continuity. The 45 WS has one of the most complex lightning advisory requirements in operational meteorology (Weems et al., 2001). A Phase-1 lightning advisory is issued when lightning is forecast with a desired lead-time of 30 min for one or more of the 13 often overlapping 5-NM circles (Figure 2). A Phase-2 advisory is issued when lightning is imminent or occurring within any of the circles. The lightning advisories are cancelled when no longer needed. This level of detailed lightning advisories is required since so much of ground processing is done in the weeks or months before a space launch. Much of this activity is on the launch pads, which are tall isolated relatively narrow structures in wide- open areas—prime targets for lightning strikes. These lightning advisories are critical for the safety of over 25,000 people and resource protection of over $18 billion in facilities. Depending on what payloads and rockets are at the launch pads or in transit outside, several more $billion may be added to this resource protection figure.

CGLSS is also used to verify the 45 WS lightning advisories in near real-time. Finally, CGLSS data are used to confirm ground strikes implied by the Lightning Detection And Ranging (LDAR) system, one of the first 4-D lightning detectors in operational meteorology. LDAR loses detection efficiency below 1 km of altitude, so it usually doesn't track cloud-to-ground lightning all the way to the ground. CGLSS flashes are overlaid on the LDAR display to help confirm that the flash struck the ground. Finally, CGLSS database is shared with other government agencies to aid in wildfire control in east central Florida.

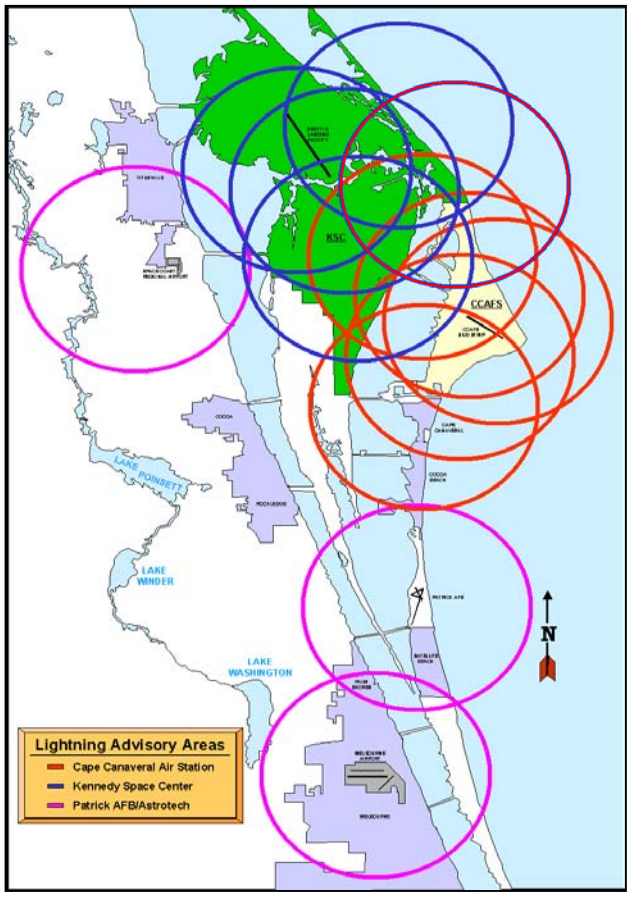


**Figure 2.** 45 WS Lightning Advisory Areas. Each of the thirteen circles represents a point for which 45 WS issues two-tiered advisories for lightning within 5 NM of the point.

## 3. USES OF SAVED OBSERVATIONS--THE CGLSS DATABASE

The 45 WS and their customers also have many uses for the past observations from CGLSS. These uses serve five basic needs: 1) climatological studies, 2) equipment retests and validation, 3) post fire analysis, 4) manpower and labor scheduling analysis, and 5) electric power availability analysis. The past CGLSS observations are stored by Computer Sciences Raytheon, the Range Technical Services contractor. These data are saved as ASCII flat files and stored on CD-ROM (formerly 9-track

computer tape). These data include the latitude/longitude, time, peak current, and polarity for the first return-stroke of all lightning flashes observed by CGLSS. That only the first return-stroke is reported is a problem. Recent lightning research has shown that 35% of cloud-to-ground lightning have multiple return-stroke locations and when multiple return-stroke locations occur, their geometric mean spacing is about 2 Km (Valine and Krider, 2002). This distance can be extremely important in evaluating the electromagnetic pulse impact on payloads and rockets. Only one return-stroke is reported since the CGLSS doesn't have sufficient computer power to report all return-strokes in real-time. In addition, the frequency of multiple return-stroke locations and the distance between them was not recognized when CGLSS was designed. The first return-stroke is chosen to be reported since it usually has the highest peak current of all the return-strokes. While CGLSS data can be processed after-the-fact to recover all return-strokes, the CGLSS database is based on the operational data and has only the first return-stroke reported.

In 2002, the 45 WS teamed with the Air Force Academy to convert the 1987-2001 CGLSS observations into an EXCEL spreadsheet database to facilitate use of that data. This conversion was done under the Air Force Academy (AFA) Cadet Summer Research Program, which assigns cadets to operational AF units for 8 weeks to conduct operational research projects. Cadet Jill Erdman was the primary worker. The 45 WS has found the CGLSS database so useful, they have continually updated it. The current CGLSS now contains observations from 1987 through 2003 and continued updates into the future are planned.

### 3.1 Climatological Studies

Climatological studies are done to support customer requirements and to improve 45 WS forecasting capability. An example of customer requirements using past CGLSS data was advising the Pegasus launch team on their ground-processing concept of operations for a March launch. Pegasus is a relatively small rocket that is launched after release from a L-1011 aircraft flying at jetliner altitude. The CGLSS database was used to estimate the local lightning flash density at the CCAFS Skid Strip during the time they would be deployed there. They have a portable lightning protection system to protect against accidental ignition of its fuel and on-board self-destruct explosives. But working under their lightning protection system slows their ground processing operations. The climatological local lightning flash density indicated the risk was acceptably small and they planned to do their ground processing outside of the lightning protection system. They were confident in that decision since 45 WS also advised them that if thunderstorms did occur at that time of the year, they would be synoptically driven and they could be informed with more than a 2-hour notice to allow them to stop ground processing and taxi under the lightning protection system.

Another example of use of the CGLSS for the 45 WS customers is cross-validating the lightning protection systems at CCAFS/KSC. Some of the launch pad lightning protection systems record when the lightning struck and the lightning's peak current. The data from CGLSS are used to validate the lightning protection system's performance. A few years ago, this validation with CGLSS detected the protection system at the space shuttle launch pad was over-estimating the lightning intensity by a factor of 2x. A subsequent investigation discovered damage to the grounding system that was causing an impedance mismatch, in essence causing the lightning to reflect back up the down conductor, causing the detector to measure the same lightning twice. This is important, since over-estimating the strength of lightning hitting the system will drive too high a level of inspection of launch pad electronics, wasting money and impacting the launch schedule. At least this is better than the lightning protection system underestimating the strike's strength, since that would lead to required inspections not being performed and degrading safety. The data from lightning strikes to recording lightning protection systems is also used to cross-calibrate and cross-validate the CGLSS location and strength performance. Calibration ensures optimal performance. Validation measures that performance, which is used to set the thresholds for inspection of payload and rocket electronics. The CGLSS location performance is also calibrated and validated via video triangulation of lightning strikes.

An example of using CGLSS in forecast improvement initiatives is the recent task assigned to the Applied Meteorology Unit to invent a tool to forecast lightning probability in the 45 WS lightning advisory areas (Figure 2). This tool used CGLSS data as the ground truth for a multi-variate logistic regression (Lambert et. al., 2005). Multiple candidate predictands were screened with the optimal combination selected for each month during the 45 WS summer thunderstorm season (May-Sep). Typical variables were the climatological probability for the seven wind-stratified flow regimes for the Florida peninsula (Lericos et al., 2002), some sort of stability index, 1-day persistence, and mid-layer mean humidity. Preliminary results indicate this new tool will provide 49% better skill than the current objective tool used by 45 WS.

Another forecast improvement example of CGLSS was the recent 'Statistical Forecasting Of Lightning Cessation - Phase-1' project under the NASA Faculty Fellowship Program. This project brought Dr. Glover from Oral Roberts University to 45 WS for 9 weeks during the summer of 2004 to investigate improved methods of terminating 45 WS lightning advisories. Canceling lightning advisories sooner with skill, while maintaining safety, is one of the most critical areas of desired improvement for 45 WS. The CGLSS database provided the ground truth for this initiative. The results from Phase-1 were successful and it is hoped that this research will be funded further. More details on this project are at (Roeder and Glover, 2005).

Researchers interested in using the CGLSS database on projects beneficial to 45 WS and their customers are encouraged to contact the corresponding author. The 45 WS is always interested in facilitating mutually beneficial operational research (Roeder and Madura, 2004) (Roeder et al., 2003) (Roeder at al., 2002).

### 3.2 Equipment Retests And Validations

The CGLSS database is used to assist equipment retests and validations. Sometimes unexpected problems are discovered with payload and rocket electronics.

Knowing the source of the problem is useful to determine corrective and preventive actions. The CGLSS database is used to estimate the likelihood that induced currents from direct lightning strikes or electromagnetic pulse from nearby strikes may have caused the damage. This is very similar to the primary real-time use of CGLSS, but is applied after-the-fact with the saved CGLSS data.

### 3.3 Post Fire Analysis

Wild fires are a persistent problem in the 45 WS area. The source of wild fires is always determined to improve future control measures. As mentioned above, since cloud-to-ground lightning is a frequent source of those wildfires, the real-time CGLSS data is used to determine if lightning caused specific wildfires. However, sometimes the cause of a wildfire cannot be determined, or the suspected cause turns out not to be true. In that case, the CGLSS database will be double checked to see if lightning might have been the source.

### 3.4 Manpower And Labor Scheduling Analysis

Manpower and labor scheduling analysis is actually a subcategory of climatological analysis. Climatology of lightning within the lightning advisory areas (Figure 2) can estimate how often and the duration lightning advisories for that point versus time of day and time of year. This climatology can then be used to estimate the impact those lightning advisories will have on scheduled outdoor work required to process a space launch vehicle for a specific launch date. The climatology can also be used to optimize the scheduling of personnel for outdoor processing, finding the best balance between nighttime premium pay with less lightning downtime and staying on launch schedule.

### 3.5 Electric Power Availability Analysis

The KSC has used past CGLSS data for an analysis of lightning impacts on electric power availability to KSC. The results were then used to analyze the cost-effectiveness of various options to improve the reliability of electric power delivery. This was done as a joint study with the local electric power industry.

## 4. FUTURE PLANS

The 45 WS plans to continually update the CGLSS database into the future. This will be done to continue supporting the customer and internal requirements discussed above and to support the inevitable new requirements.

In addition, the 45 WS wants to upgrade CGLSS to overcome the problem of only the first return-stroke being reported, as discussed previously. In principle all return-strokes could be added to the CGLSS database now, since all return-strokes can be analyzed via post-processing of the original data. However, this is too labor intensive and is only done for special cases, such as calibrating CGLSS against ground truth from timed video triangulation and strikes to recorded lightning protection systems.

The Kennedy Space Center has developed and deployed a new system for cloud-to-ground lightning detection, the Sonic Lightning Locater (SoLLo) (Medelius et. al., 2002). SoLLo will have extreme accuracy but over a very restrictive range, 5 m and 1 Km, respectively. While SoLLo will not totally replace CGLSS, if purchased for the other launch pads, it could replace CGLSS for estimating the electromagnetic pulse impacts on the payloads and rockets at the launch pads.

## 5. SUMMARY

The 45 WS maintains a database of past observations from CGLSS, their local high-performance cloud-to-ground lightning detector. This database has many diverse uses, such as, 1) climatological studies, 2) equipment retests and validation, 3) post fire analysis, 4) manpower and labor scheduling analysis and 5) energy analysis. This database is available for use by external researchers on projects beneficial to 45 WS and their customers.

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