P2.4 Installation, Upgrade, and Evaluation of a Short Baseline Cloud-to-Ground Lightning Surveillance System Used to Support Space Launch Operations

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1. INTRODUCTION

The Air Force's 45th Weather Squadron (45 WS) provides comprehensive operational meteorological services to the Eastern Range (ER) and the Kennedy Space Center (KSC) in east central Florida. These services include weather support for pre-launch ground processing, launch, recovery, routine 24/7 weather advisories for personnel safety and resource protection, and special missions. The 45 WS supports all launches at Cape Canaveral Air Force Station (CCAFS) and KSC for the Department of Defense, National Aeronautics and Space Administration (NASA), and commercial launch customers.

To assess weather's impact on all phases of launch operations, the 45 WS operates an extensive meteorological instrumentation network (Harms et al., 2003). This paper addresses only one of those systems: the Cloud-to-Ground Lightning Surveillance System (CGLSS).

2. CGLSS REQUIREMENTS

Lightning is a major concern to all aspects of launch operations. This concern is more significant in the CCAFS/KSC area since the area of maximum thunderstorm occurrence in the United States is in Central Florida, not far from the CCAFS/KSC complex. Consequently, thunderstorms represent the single greatest threat to operations on CCAFS/KSC, bringing deadly lightning and damaging winds. Table 1 shows the diurnal and monthly frequency of thunderstorms for those months either side or encompassing the thunderstorm season at the Shuttle Landing Facility (SLF) from 1973-2003 (AFCCC, 2004). These data clearly show a thunderstorm maximum in the summer afternoons, reaching 21 percent of hourly observations for 1500 to 1700 Local Standard Time in July. Days with thunderstorms (as opposed to hourly data) exceed 50 percent in both July and August. The number of cloud-to-ground strikes per year is widely variable within the CCAFS/KSC complex. The annual average ranges from 5 to 13 flashes per km^2 (Boyd et al., 1995). CGLSS climatological data and its uses are addressed in an accompanying paper (Roeder and Weems, 2005).

The CGLSS is deployed in and around the launch and operations areas to meet the requirements for high quality location accuracy, detection efficiency, and peak current of local cloud-to-ground lightning strikes (Harms et al., 1997). The main requirement is to estimate the electro magnetic impulse impact on the sensitive electronics in payloads and launch vehicles. If a cloud-to-ground lightning strike exceeds specified distance and peak current thresholds, various inspections must be completed. Level of action varies based on the intensity and distance of the lightning strike. All inspections are time-consuming and expensive, so high quality lightning detection is required to avoid needless inspections. A second benefit of CGLSS is lightning forecasting through continuity from previous lightning. A third use is analysis of past observations in various climatological applications (Roeder and Weems, 2005).

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TABLE 1
Percent of Hourly Observations with Thunderstorms at the KSC Shuttle Landing Facility (1973-2003) (AFCCC, 2004)

LST	APR	MAY	JUN	JUL	AUG	SEP
00-02	1	1	1	1	2	2
03-05	1	1	1	1	1	2
06-08	-	1	1	1	1	2
09-11	1	1	3	2	3	3
12-14	3	4	13	14	14	8
15-17	3	6	17	21	19	10
18-20	3	5	10	11	10	7
21-23	1	2	4	3	4	4

3. CGLSS DESIGN HISTORY

The original installation of the Cloud-to-Ground Lightning Surveillance System (CGLSS) at CCAFS/KSC was completed prior to the first Shuttle launch in 1981. A test system with three sensors was installed during the 1 June – 12 July 1979 period with leased equipment at KSC, as part of the Federal Evaluation of Lightning Tracking System (FELTS). The system was then procured in February 1981 with joint funding by NASA and the Air Force. In August 1983, a contract was awarded to add a low gain system. By February 1984, the system consisted of two low gain direction finders (DFs) located at the Titusville-Cocoa Airport and Merritt Island, and three medium gain DFs located at the same Merritt Island location and the Orlando and Melbourne Airports (Boyd, et al,, 1985) (Figure 1). From 1984, the system continued under development and was accepted into the ER inventory as a fully certified system 24 July 1989. From 1989 to 1994 the system was further upgraded to a network of five LLP Model 141 Advanced Lightning Direction Finders (ALDF). During the 1995-1998 period the system was converted to a short-baseline 6-antenna magnetic direction-finding/time-of-arrival IMProved Accuracy from Combined Technology (IMPACT) system (Harms, et al., 2001). In 2002, the Air Force received notice that the lease at Duda Ranch (site #3) could not be renewed, which required relocation of the site #3 sensor (Figure 2). The replacement site #3 from Duda to the Deseret Ranch location would maintain the six-sensor network and have the added advantage of providing additional redundancy of east-west line of sight to CCAFS/KSC. The other sensors with east-west line of sight can have reliability problems. The Seminole Ranch sensor (site #4) is subject to flooding and both this sensor and the Tosohatchee sensor (site #6) are both in areas of high lightning flash densities, which increases the risk of damage.

The Range Technical Services contractor, currently Computer Sciences Raytheon (CSR) maintains CGLSS. This contractor also conducts an on-going program of ground-truth verification. Ground-truth is available by videotape triangulation and when lightning strikes the local lightning protection systems that have inline detectors.

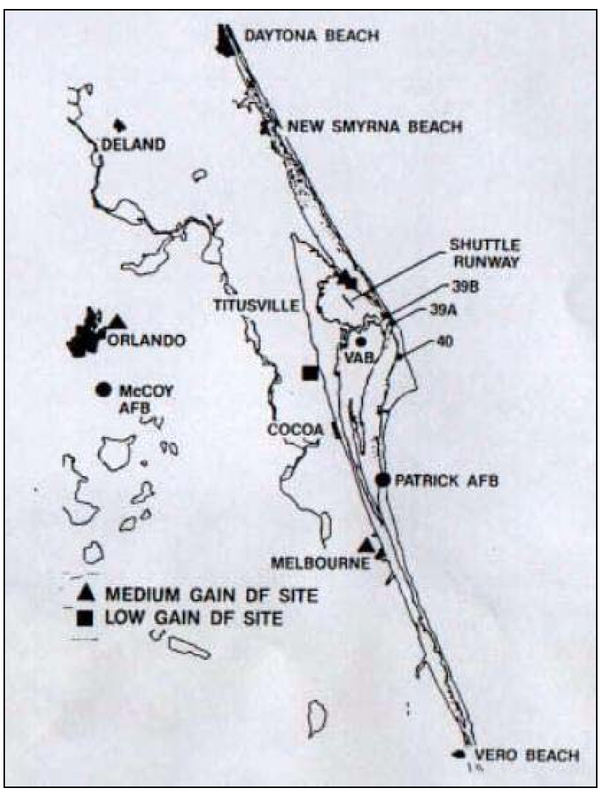

Figure 1. 1984 CGLSS Configuration

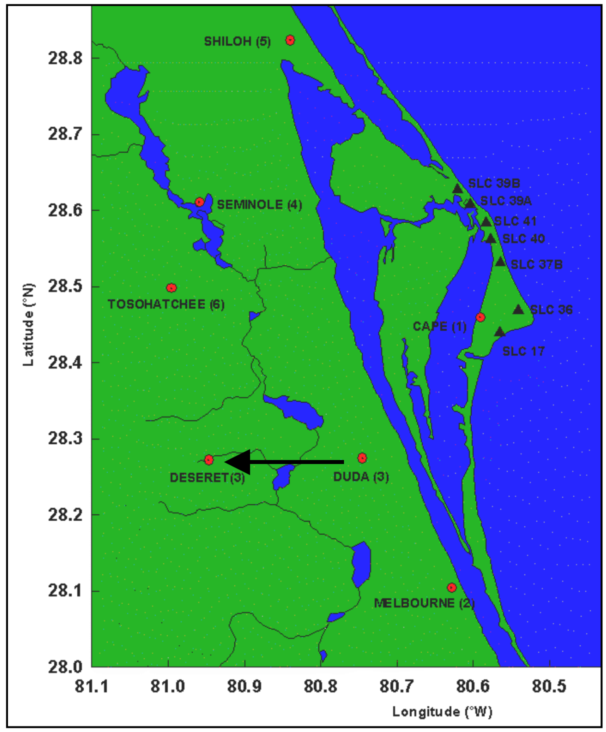

Figure 2. 2004 Configuration (Both locations for site 3, moved from Duda to Deseret shown)

4. CGLSS PERFORMANCE EVALUATION

The performance of the six-sensor CGLSS, prior to movement of the Duda site (discussed below) is listed in Table 2. This performance meets or exceeds the operational requirements and provides a degree of redundancy and excess capability in case a loss of sensors occurs.

TABLE 2

Performance of the current 6-sensor CGLSS (before move of one sensor to Deseret Ranch).

Location Accuracy 50% confidence 95% confidence	 250 m 300 m
Detection Efficiency	98%
False Detection Rate	5%
Peak Current	20%

The operational customers were concerned about the degraded performance of CGLSS during the move of the sensor from Duda to Deseret Ranch, especially if an additional sensor were lost. To alleviate concerns, the Operations Analysis section of CSR estimated the expected CGLSS performance under various combinations of sensors, given that the Duda/Deseret sensor was not available. The vendor, Vaisala Inc., provided valuable assistance during the study. Table 3 shows the location accuracy estimates from the CSR study. The accuracy is measured from a location between Space Launch Complexes (SLC) 40 and 41 on the northeast coast of CCAFS (Figure 1). The operational requirements are still met by most four-sensor configurations, i.e. another sensor unavailable, in addition to the Duda/Deseret sensor. Note that for a single additional sensor outage (i.e. four sensors up), sites #1 (Cape) and #5 (Shiloh) are the more critical (see bolded lines 4 and 6 in Table 3). Most three-sensor configurations do <u>not</u> meet operational requirements, i.e., two additional sensors missing. Figures 3 and 4 show typical plots (values are shown for 0.3, 0.5, 1.0, 2.0, 4.0, and 8.0 km) of location accuracy (50% confidence), which went into building the Table. Under the best case of all five sensors available (Duda/Deseret Ranch sensor not yet moved) (Figure 3), *all of CCFAS/KSC* has a location accuracy of 300 m (50% confidence), which exceeds the operational requirements). Under the worst-case two-sensor configuration, the 50% confidence location accuracy across CCAFS/KSC averages just less than 3 km, varying widely from 1.5 – 4+ km (Figure 4). This fails to meet the operational requirements.

TABLE 3
Expected Accuracy for Different Sensor Combinations

Site Combinations	1	2	3	4	5	6	50% Confidence (km)	95% Confidence (km)
1,2,4,5,6	X	X		X	X	X	0.30	0.38
1,2,5,6	X	X			X	X	0.30	0.38
1,2,4,5	X	X		X	X		0.30	0.38
1,2,4,6	**X**	**X**		**X**		**X**	**0.50**	**0.64**
1,4,5,6	X			X	X	X	0.30	0.38
2,4,5,6		**X**		**X**	**X**	**X**	**0.50**	**0.64**
1,2,4	X	X		X			0.50	0.64
1,2,5	X	X			X		0.30	0.38
1,2,6	X	X				X	0.50	0.64
1,4,5	X			X	X		0.30	0.38
1,4,6	X			X		X	0.50	0.64
1,5,6	X				X	X	0.30	0.38
2,4,5		X		X	X		0.50	0.64
2,4,6		X		X		X	1.00	1.27
2,5,6		X			X	X	0.50	0.64
4,5,6				X	X	X	1.00	1.27
1,2	X	X					4.00	5.08
1,4	X			X			0.50	0.64
1,5	X				X		0.30	0.38
1,6	X					X	0.50	0.64
2,4		X		X			1.00	1.27
2,5		X			X		1.00	1.27
2,6		X				X	1.00	1.27
4,5				X	X		2.00	2.54
4,6				X		X	4.00	5.08
5,6					X	X	2.00	2.54

Site Locations: Site 1 Cape, Site 2 Melbourne, Site 3 Deseret (not installed for study), Site 4 Seminole, Site 5 Shiloh, Site 6 Tosohatchee.

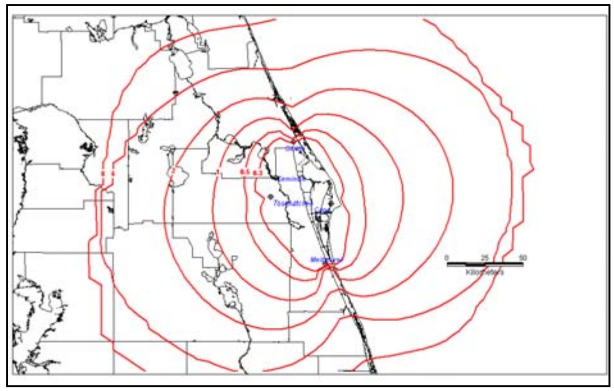

Figure 3. Location accuracy (km) (50% confidence) under the best five-sensor configuration (with Duda/Deseret Ranch sensor not available). Isopleth values are for 0.3, 0.5, 1.0, 2.0, 4.0, and 8.0 km.

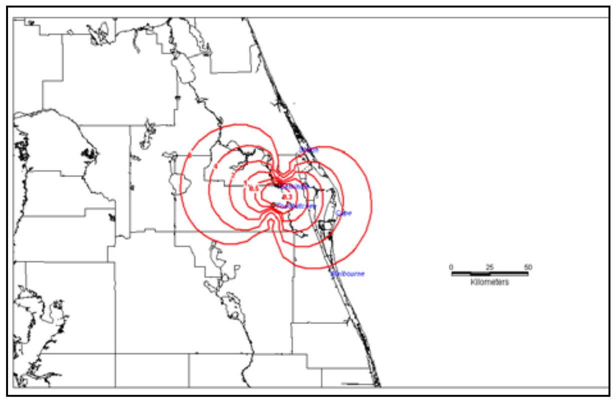

Figure 4. Location accuracy (km) (50% confidence) under the worst two-sensor configuration (with Duda/Deseret Ranch sensor not available). Isopleth values are for 0.3, 0.5, 1.0, 2.0, 4.0, and 8.0 km.

While the system has the following attributes: (1) Detection efficiency, (2) False classification rate (in-cloud versus cloud-to-ground), (3) Locating accuracy, and (4) Peak current accuracy; all evaluations were based on location only, using the following evaluation methods: (1) Ground truth (direct strikes to instrumented structures, video), (2) Self-consistency of responses from multiple stations to same lightning, and (3) Comparison with other lightning detection systems.

5. FUTURE PLANS

The CGLSS firmware is currently being upgraded. This should produce minor performance improvements and standardize the sensors with those in the National Lightning Detection Network, facilitating future maintenance. The lightning grounding of CGLSS, and other local sensors, are also being upgraded to improve their survivability from nearby lightning strikes. The CGLSS is also being integrated into the 45 WS AWIPS as their primary display system in the near future.

The on-going ground-truth performance verification will continue for optimal performance. In the long-term, additional calibrations will be considered. Additionally, the 45 WS would like to upgrade CGLSS to detect all cloud-to-ground lightning return-strokes, rather than just the first and usually strongest return-stroke. Recent research shows that more lightning has multiple return-stroke ground points (~40%), and the distance between ground points) is longer than previously believed (mean ~3 Km. The CGLSS can already detect all return-strokes when analyzing after-the-fact data, but significantly faster computer processors will be required to do this in real-time to support operations.

6. SUMMARY

The Cloud-to-Ground Lightning Surveillance System is a high-performance local cloud-to-ground lightning detection system, which supports operations to America's space program at CCAFS/KSC. The CGLSS requirements and design history were discussed with a special emphasis on performance under various sensor configurations.

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