VERIFICATION OF THE UNITED STATES PRECISION LIGHTNING NETWORK™ (USPLN™) WITH THE CLOUD-TO-GROUND LIGHTNING SURVEILLANCE SYSTEM (CGLSS)

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Introduction and Background

- **WSI, Incorporated requested a performance evaluation of the United States Precision Lightning Network™ (USPLN™), co-owned by TOA Systems, Inc.**
  - Previous Studies (WSI 2010)
    - Methods: network simulations and fixed tower case studies
    - Detection Efficiency (DE) > 95% within CONUS
    - Location Accuracy < 250 m within CONUS
  - Extended validation study has yet to be completed
- **Verification Tool: The Cloud-to-Ground Lightning Surveillance System, 2nd Generation (CGLSS-II)**
  - Excellent Local Performance
    - Stroke DE: ~98%
      - Weakness: some strong local strokes sometimes missed
    - 50% Confidence Location Accuracy: 273 m
    - 95% Confidence Location Accuracy: 567 m
  - Established detection network for Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS)
  - Part of the Four Dimensional Lightning Surveillance System (4DLSS)
    - Used for total lightning detection at KSC/CCAFS
  - Integral part of the 45th Weather Squadron's (45 WS) lightning procedures
    - Phase-I lightning watches and Phase-II lightning warnings
    - Daily lightning reports
    - Lightning Launch Commit Criteria

Network Attributes

Attribute	CGLSS-II	USPLN
Network Scale	Local	International
Baseline	~30 km	~250 km
# Sensors	6 (5 as of August 2010)	100+
Sensor Model	Global Atmospherics, Inc. Model 141-T	TOA Systems, Inc. Precision Lightning Sensor™ (PLS™)
Techniques	Magnetic Direction Finding and Time of Arrival	Time of Arrival
GPS Technology	Yes	Yes
Flash/Stroke Reports	Stroke	Stroke
Recorded Event Time	Time that lightning waveform exceeds set detection threshold at nearest reporting sensor	Time of lightning waveform peak voltage

CGLSS-II attributes were provided by Flinn *et al*. (2010) and Ward *et al.* (2008) while USPLN attributes were provided by Neilley and Bent (2009).

Period of Study

Sub-period	Dates	Defining Events
I	20 May 2008 - 25 Jul 2009	20 May 2008: Inception of CGLSS-II data 26 Jul 2009: CGLSS-II Sensor #2 damaged by lightning stroke
II	11 Aug 2009 - 17 Feb 2010	11 Aug 2009: Temporary 5-sensor CGLSS configuration brought online
III	18 Feb 2010 - 31 Aug 2010	18 Feb 2010: CGLSS-II vendor configuration software reset

Periods defined by changes to CGLSS-II hardware and software that altered performance metrics used to verify the USPLN in this project.

Data and Data Processing

- **Data Sources**
  - CGLSS-II provided by 45 WS and NASA Spaceport Weather Data Archives
  - USPLN provided by WSI, Incorporated
  - 4DLSS provided by NASA Spaceport Weather Data Archives
    - Contains Lightning Detection and Ranging II (LDAR-II) data
    - For use with individual case studies
  - KMLB WSR-88D radar imagery provided by Plymouth State University's CCAFS/KSC Warm-Season Convective Wind Climatology database
    - For use with individual case studies
- **Quality Controls**
  - All Lightning Data
    - Removal of test strokes
    - Removal of repeated strokes
  - CGLSS-II Stroke Data
    - Strokes restricted to region of interest defined in Figure 1
    - Removal of strokes with peak current between 0 and +10 kA
      - Many of these are likely misclassified intra-cloud (IC) strokes
  - USPLN
    - Strokes flagged by number of inoperable Florida USPLN sensors
    - Flags used to stratify data in the stroke DE and location accuracy results

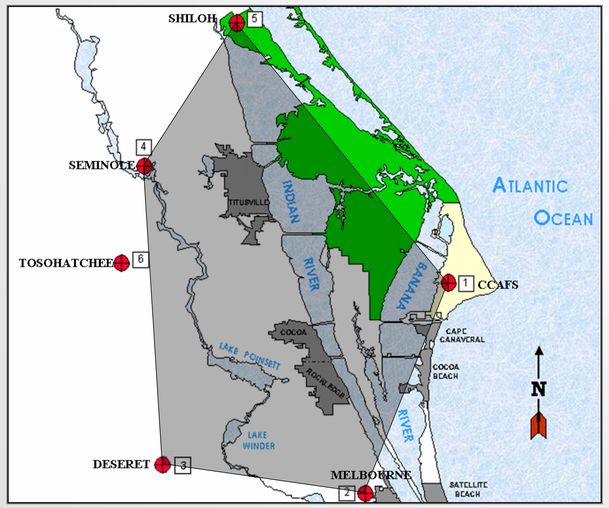

Figure 1. Map of the six CGLSS-II sensor locations and derived region of interest for this project (map provided by Lambert *et al.* 2005).

Stroke Correlation Procedure

- **Purpose**
  - Match strokes detected by both CGLSS-II and USPLN
  - Primary dataset for stroke DE and location accuracy analyses
- **Correlation Thresholds**
  - Time: USPLN stroke time within ±3 ms of CGLSS stroke time
  - Distance: ≤ 15 km between reported stroke locations
  - Thresholds based on previous studies and exploratory analysis

Detection Efficiency Procedure

- **Average Stroke DE**
  - For each day…
    - $DE = \frac{DETECTED}{CGLSS}$ and the variance $VAR = \frac{DE(1-DE)}{CGLSS}$
    - Variance defined using a normalized binomial distribution
  - Weighted average techniques used to determine average performance
    - $\overline{DE} = w_1 DE_1 + w_2 DE_2 + \ldots + w_n DE_n$
    - $\overline{VAR} = w_1^2 VAR_1 + w_2^2 VAR_2 + \ldots + w_n^2 VAR_n$
    - Weights (w) based on number of CGLSS-II strokes per day
- **Variation by Peak Current**
  - Previous Studies
    - Stroke DE decreases with decreasing peak current magnitude
  - Method 1: Logistic Regression
    - Predictor: CGLSS-II peak current readings
    - Binomial Response: Detection of the CGLSS-II stroke by the USPLN
    - Determine relationship strength between predictor(s) and response
  - Method 2: Histograms
    - Plot stroke frequencies versus peak current (see Figure 2)
- **Variation by Spatial Characteristics**
  - Hypothesis
    - Undetected strokes by the USPLN may be subsequent strokes in a flash
      - Typically found within 10 km of the first stroke
  - Method
    - R Foundation for Statistical Computing
      - Statistical software program
      - Provides packages built for spatial statistics
      - Used in this study to examine possible clustering of undetected strokes near a detected stroke

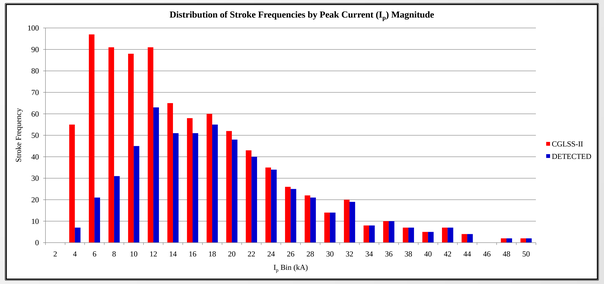

Figure 2. Histogram of stroke frequencies by CGLSS-II peak current magnitude for 15 June 2010.

Location Accuracy Procedure

- **Known Parameters**
  - Distance between correlated strokes
    - Derived using Great Circle Distance Formula
  - Location error for CGLSS-II (95% confidence)
- **Assumptions**
  - CGLSS-II and USPLN location errors are independent
- **Method**
  - Total error is the addition of perpendicular error vectors
  - Derive USPLN location error (95% confidence) for each stroke
  - Calculate daily median and variance measurements for USPLN location errors
  - Utilize weighted average techniques to determine average performance

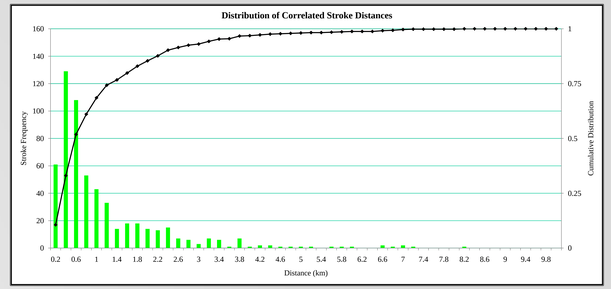

Figure 3. Histogram and cumulative distribution plot of correlated stroke frequencies by distance for 15 June 2010.

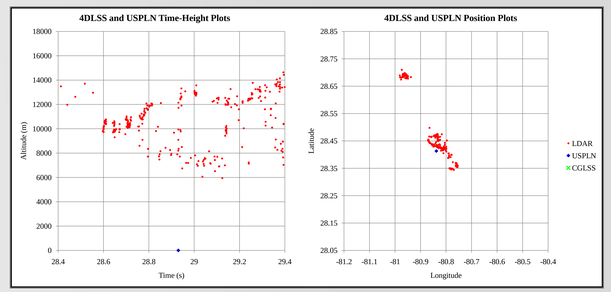

Figure 4. Example of a case-study plot using 4DLSS to aid in identifying a possible misclassified USPLN stroke. Plots are for one second of data starting on 15 June 2010 at 17:29:28.4 UTC.

Selected References

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