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

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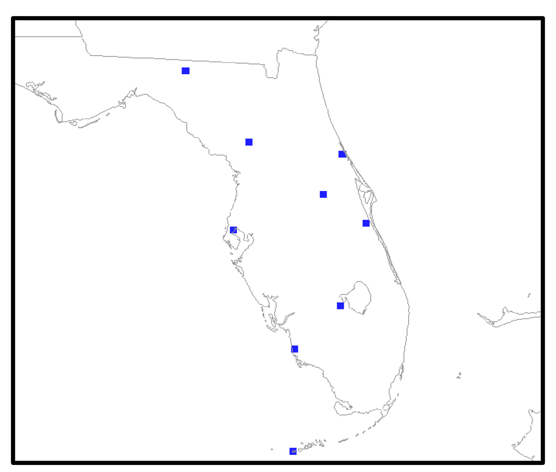
Introduction and Background

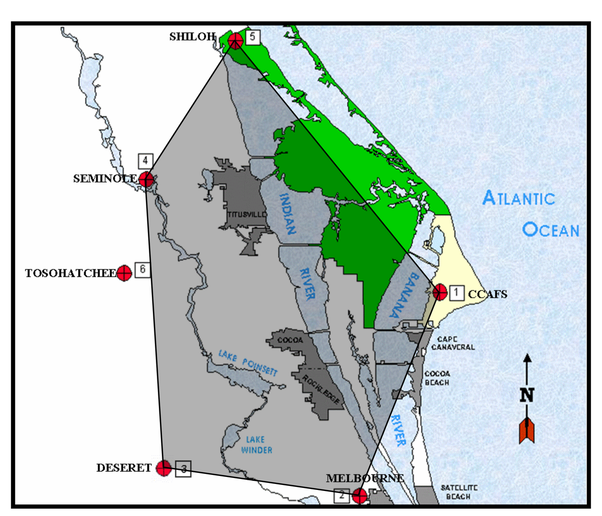
- **WSI Corporation requested a performance evaluation of the United States Precision Lightning Network™ (USPLN™), co-owned by TOA Systems, Inc.**
  - Previous network simulations and fixed tower analyses used to establish performance (WSI 2010)
    - Detection Efficiency (DE) > 95% within CONUS
    - Location Accuracy < 250 m within CONUS
  - Extended performance evaluation yet to be completed
- **Comparative Network: The Cloud-to-Ground Lightning Surveillance System, 2nd Generation (CGLSS-II)**
  - Excellent local performance inside network bounds
    - Stroke DE: ~98%
      - Weakness: some strong local strokes sometimes missed due to sensor saturation
    - 50% Confidence Location Accuracy: 273 m
    - 95% Confidence Location Accuracy: 567 m
  - Established network for Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS)
  - Detects CG lightning as a portion 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 warnings
    - Daily lightning reports
    - Lightning Launch Commit Criteria
- **Important Network Attributes**

Attribute	CGLSS-II	USPLN
Network Scale	Local	International
Sensor Baseline	~30 km	~250 km
Techniques	Magnetic Direction Finding and Time of Arrival	Time of Arrival
GPS Technology	Yes	Yes
Flash/Stroke Reports	Stroke	Stroke

- **USPLN Florida Sensor Locations**



- **CGLSS-II Sensor Locations and Selected Study Region (provided by Lambert *et al.* 2005)**



Data and Methodology

- **Data Sources**
  - CGLSS-II stroke data: 45 WS and NASA Spaceport Weather Data Archives
  - USPLN stroke data: WSI
  - 4DLSS: NASA Spaceport Weather Data Archives
    - Contains Lightning Detection and Ranging II (LDAR-II) data
  - KMLB WSR-88D composite reflectivity radar imagery: NCDC and Plymouth State University's CCAFS/KSC Warm-Season Convective Wind Climatology database
- **Data Quality Controls**
  - Removal of any test and repeated strokes
  - CGLSS-II stroke data:
    - Strokes restricted to selected study region
    - Eliminated strokes with I_p between 0 and +10 kA
      - Portion of these likely misclassified IC strokes
  - USPLN stroke data:
    - Strokes flagged using Florida USPLN sensor outage data provided by WSI
- **Selected Period of Study**
  - 20 May 2008 – 30 Jun 2010
  - Stratified into the following sub-periods:

Sub-Period	Dates	Defining Events
I	20 May 2008 – 25 Jul 2009	20 May 2008: Beginning of available 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 online
III	18 Feb 2010 – 30 Jun 2010	18 Feb 2010: CGLSS-II vendor configuration software reset

- **Stroke Correlation Procedure**
  - Matched strokes detected by both CGLSS-II and USPLN
  - Dataset for stroke DE and location accuracy analyses
  - Correlation thresholds:
    - Time: USPLN time within ±3 ms of CGLSS time
    - Distance: ≤ 15 km between both stroke locations
    - Thresholds based on previous studies and exploratory analysis
- **USPLN Stroke DE**
  - Peak current variation
    - Previous studies had shown a relationship between stroke DE and stroke peak current
    - Method 1: logistic regression
      - Predictor: CGLSS-II $|I_p|$ magnitude
      - Response: USPLN detection of the stroke
      - Determined initial relationship strength
    - Method 2: discrete plots
      - Plot ted stroke frequencies of CGLSS-II and detected USPLN strokes using 2 kA $|I_p|$ bins
      - Derived Stroke DE curves by calculating DE
  - Stroke rate variation
    - Did the USPLN performance change with little or plentiful lightning activity?
    - Derived CGLSS-II stroke rates (strokes km^{-2} hr^{-1}) every hour when zero sensor outages occurred
    - Determined USPLN stroke DE for each stroke rate and plotted stroke DE versus CGLSS-II stroke rate to view a possible relationship

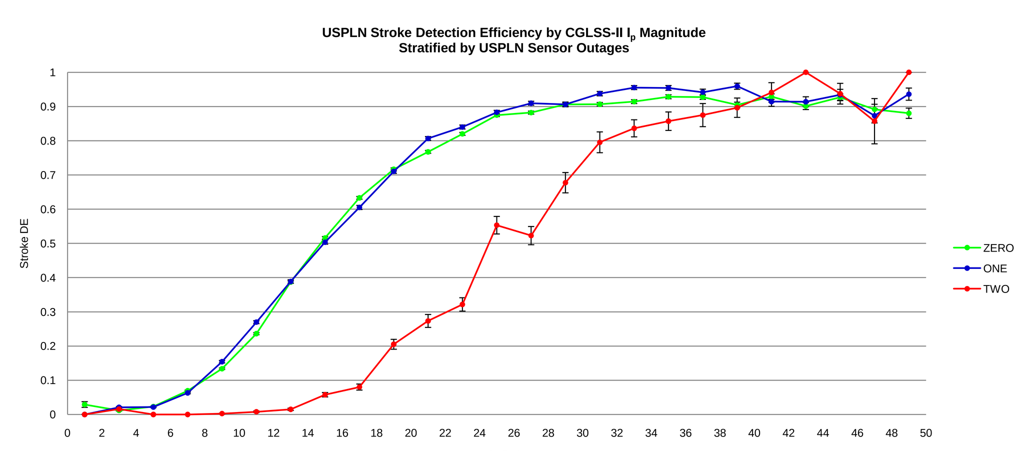
- **USPLN Location Accuracy**
  - Known parameters:
    - Matching stroke distances (correlation procedure)
    - 95% confidence CGLSS-II location errors
      - Sub-period I: 693 m
      - Sub-period II: 981 m
      - Sub-period III: 567 m
  - Assumed CGLSS-II & USPLN errors are independent
  - Total error = the addition of perpendicular error vectors
    - Used Pythagorean Theorem to derive 95% confidence USPLN location error for each stroke
    - Determined daily median error and variance
  - Weighted averaging used for overall performance
    - $\overline{LE} = w_1LE_1 + w_2LE_2 + ... + w_nLE_n$
    - $\overline{VAR} = w_1^2VAR_1 + w_2^2VAR_2 + ... + w_n^2VAR_n$
- **Case Studies**
  - Selections: 5 September 2009 and 15 June 2010
  - 4DLSS analysis:
    - Uncorrelated USPLN Strokes in the study region
    - Strokes were classified as CG, IC, "phantom", or unclassified based on plots using 4DLSS data
  - WSR-88D analysis:
    - "Phantom" strokes plotted with radar imagery

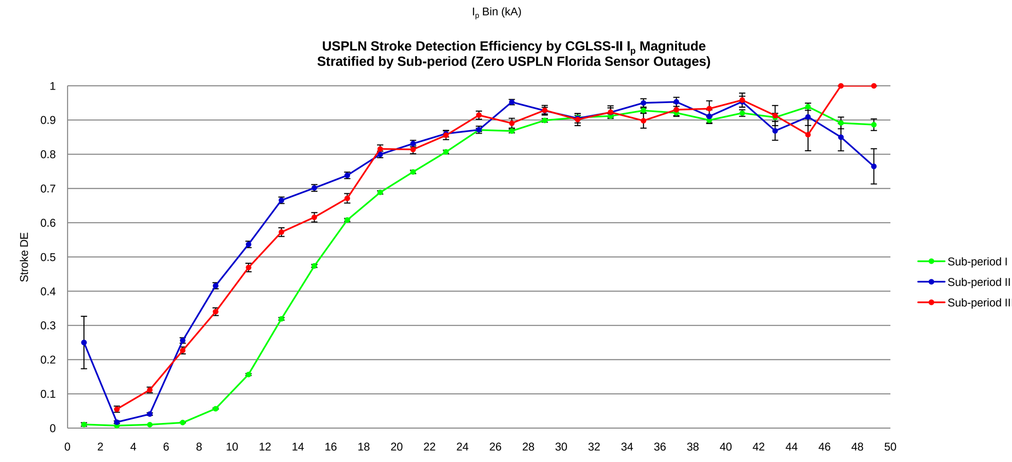
Results

- **USPLN Stroke DE vs. $|I_p|$: Logistic Regression Results**

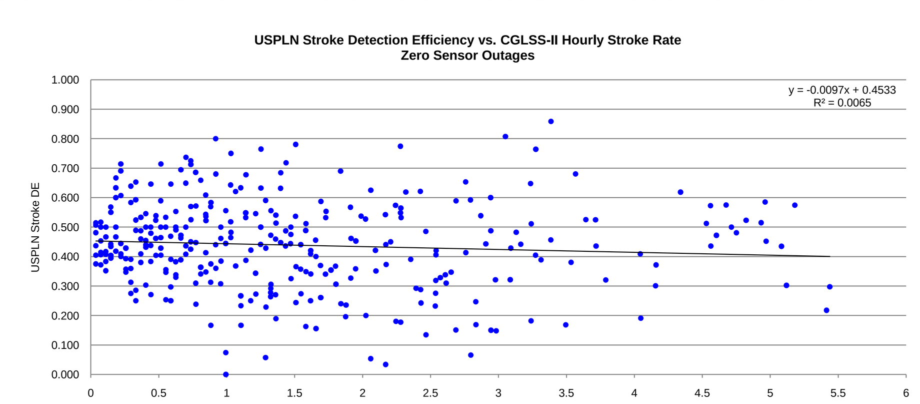
USPLN Outages	Slope	Intercept	Pseudo-r^2
Zero	0.2110	-3.4456	0.3217
One	0.2289	-3.6473	0.3391
Two	0.2092	-5.7092	0.4523

- **USPLN Stroke DE: CGLSS-II Peak Current Variation**





- **USPLN Stroke DE: CGLSS-II Stroke Rate Variation**



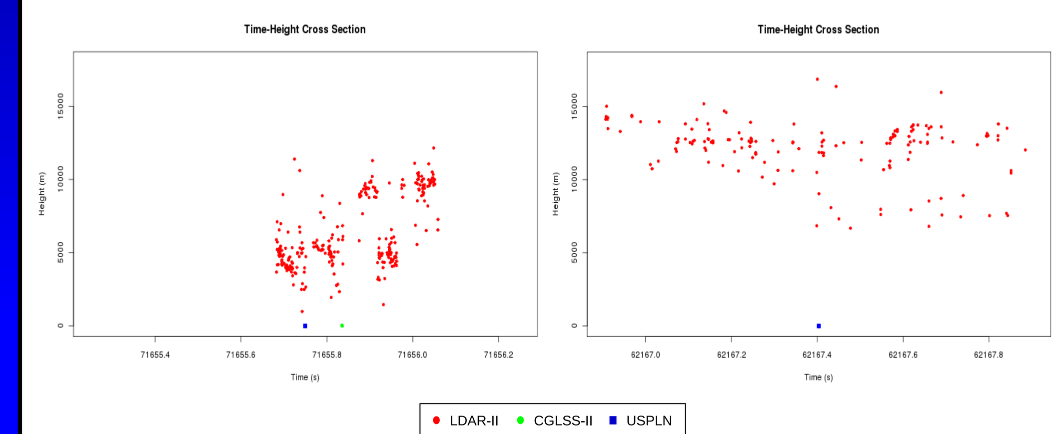
- **USPLN 95% Confidence Stroke Location Error (km)**

Sensor Outages	Sub-period I		Sub-period II		Sub-period III	
	LE	VAR	LE	VAR	LE	VAR
Zero	1.410	0.125	1.190	0.294	0.626	0.284
One	1.475	0.164	0.844	1.024	0.891	0.291
Two	1.727	0.890	NA	NA	2.137	14.075

- **Case Studies: 4DLSS Classification Results**

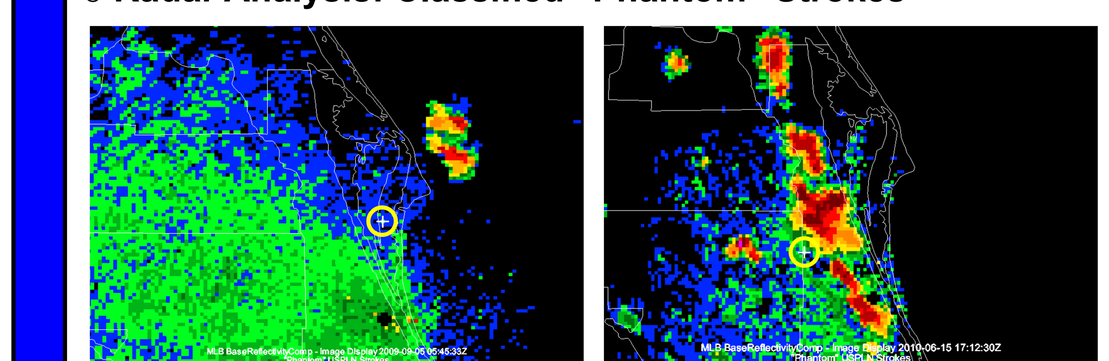
Class	5 September 2009		15 June 2010	
	FREQ	PCT	FREQ	PCT
True CG	11	15.07%	42	12.07%
Correct IC	6	8.22%	56	16.09%
Misclassified IC	40	54.79%	192	55.17%
"Phantom"	7	9.59%	5	1.44%
Unclassified	9	12.33%	53	15.23%
Total Strokes	73	100.00%	348	100.00%

- **4DLSS Time-Height Plot Examples**



USPLN CG Stroke — USPLN Misclassified IC Stroke

- **Radar Analysis: Classified "Phantom" Strokes**



5 September 2009 — 15 June 2010

Discussion

- **USPLN Strengths**
  - Clear improvement in performance recently, highlighted by strong performance metrics in sub-period III
  - Excellent detection of strong current strokes
  - Strong location accuracy, rivaling that of CGLSS-II during the latter portion of study when all sensors were online
  - Strong co-location with radar imagery
- **USPLN Weaknesses**
  - Network was sensitive to sensor outages which impacted the overall sensor baseline around the interest region
    - Drop in both stroke DE and location accuracy performance during any outages of two sensors
  - Weak detection of lower current strokes (especially for strokes with peak current below 16 kA)
    - Lack of a strong enough signal at the sensors?
    - Lack of enough sensors detecting the stroke?
  - Over-classification of USPLN IC strokes as CG strokes
    - Based on 4DLSS analysis of the two case studies

Future Work

- **Additional Study Options**
  - Additional stroke-stroke comparative studies
    - Other local networks located across the CONUS
      - Provide performance estimate for other areas
    - Other national and global networks
  - Investigation into methods to filter low current (< 10 kA) CGLSS-II strokes to distinguish IC/CG strokes
    - Likely that some IC strokes were not filtered out
    - 4DLSS useful, but not a full-proof method
  - New comparative study after new sensor implementation
    - USPLN currently testing new sensors
    - CGLSS-II eventually plans to upgrade sensors and restore 6-sensor configuration

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