KSC LC39B LPS Direct Lightning Strikes, 2011
Performance evaluation of CGLSS II and NLDN

Dr. Carlos T. Mata
Angel G. Mata

Dr. Vladimir A. Rakov

Amitabh Nag

John Saul

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Introduction

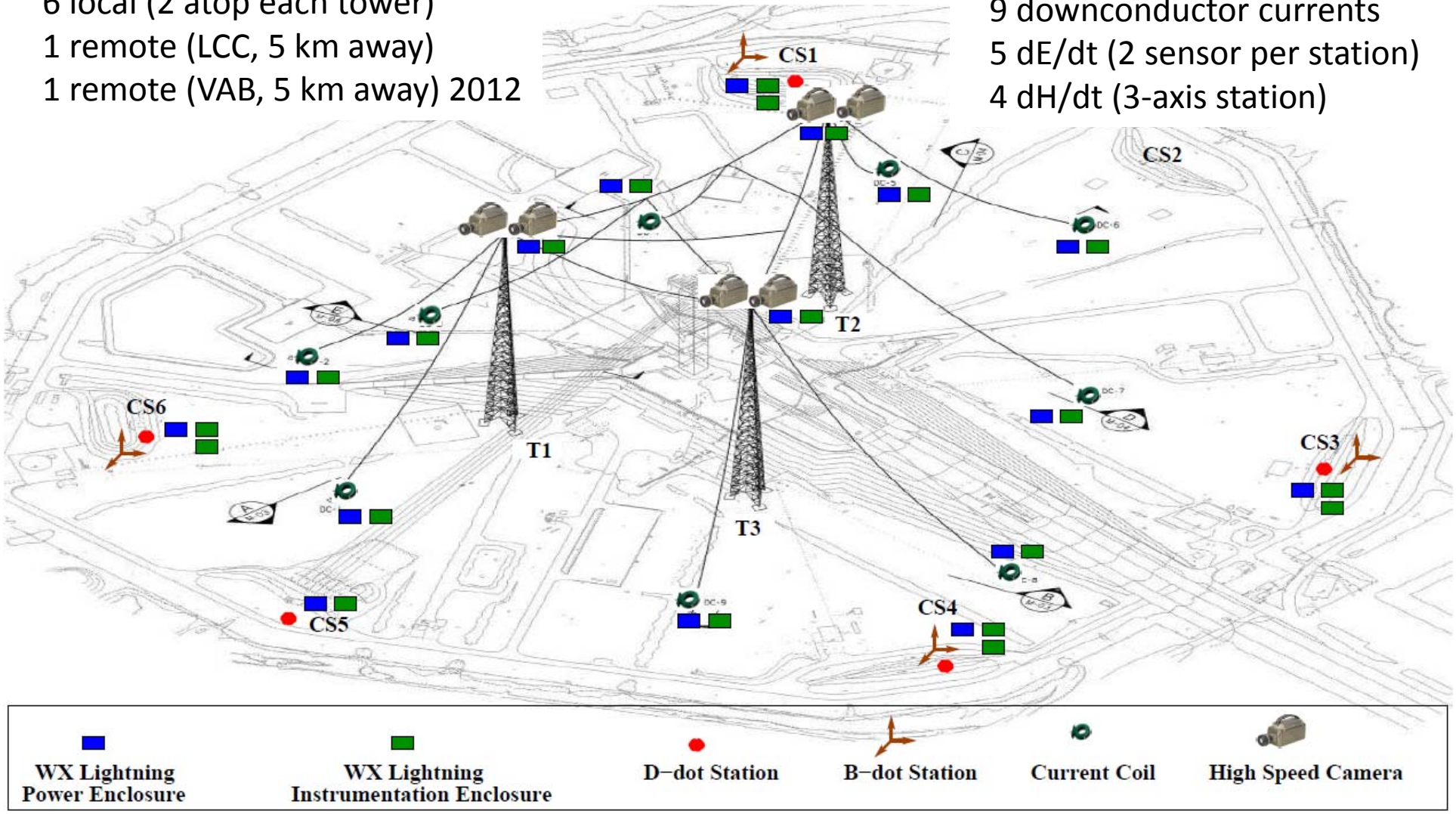
- Both NLDN and CLGSS II have been providing lightning detection and location
- 2007, LC39B Lightning Instrumentation Design
- 2011, LC39B Lightning Instrumentation Deployment
- Triggered lightning (ICLRT 2004-2009) used to provide the most recent NLDN performance characteristic
- Historical data (2005 & 2006) used to compare CGLSS II and NLDN
- LC39B LPS instrumentation provides ground-truth data

KSC Lightning Location Systems

LC39B LPS – Incrementally deployed since 2011

High Speed Video Cameras:
- 6 local (2 atop each tower)
- 1 remote (LCC, 5 km away)
- 1 remote (VAB, 5 km away) 2012

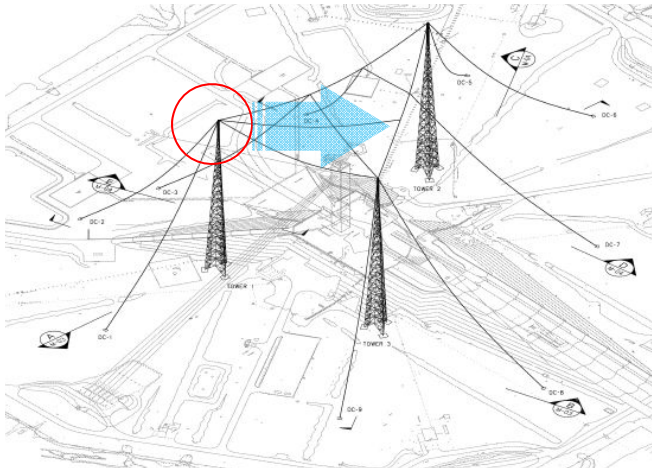
Measurements:
- 9 downconductor currents
- 5 dE/dt (2 sensor per station)
- 4 dH/dt (3-axis station)



LC39B LPS

Tower 1 Cameras Field of View

Bottom Camera:
Tower 2

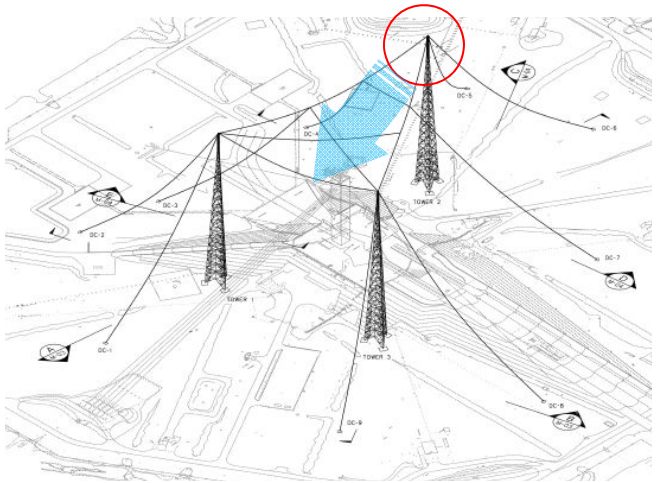


Top Camera:
Catenary (DC7) Pad A
background

LC39B LPS

Tower 2 Cameras Field of View

Bottom Camera:
Tower 3 (VAB background)

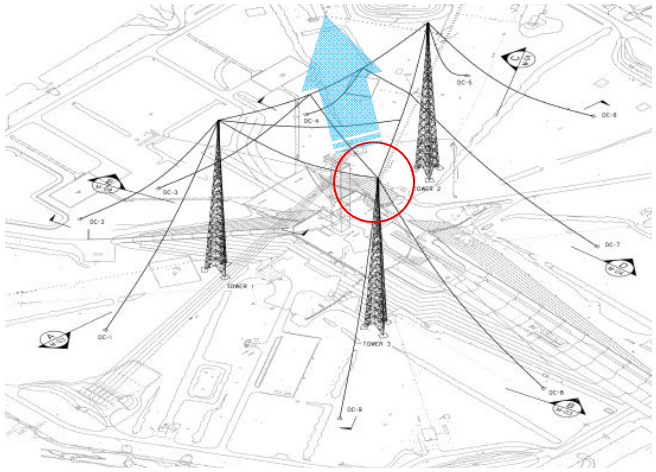


Top Camera:
Tower 1

LC39B LPS

Tower 3 Cameras Field of View

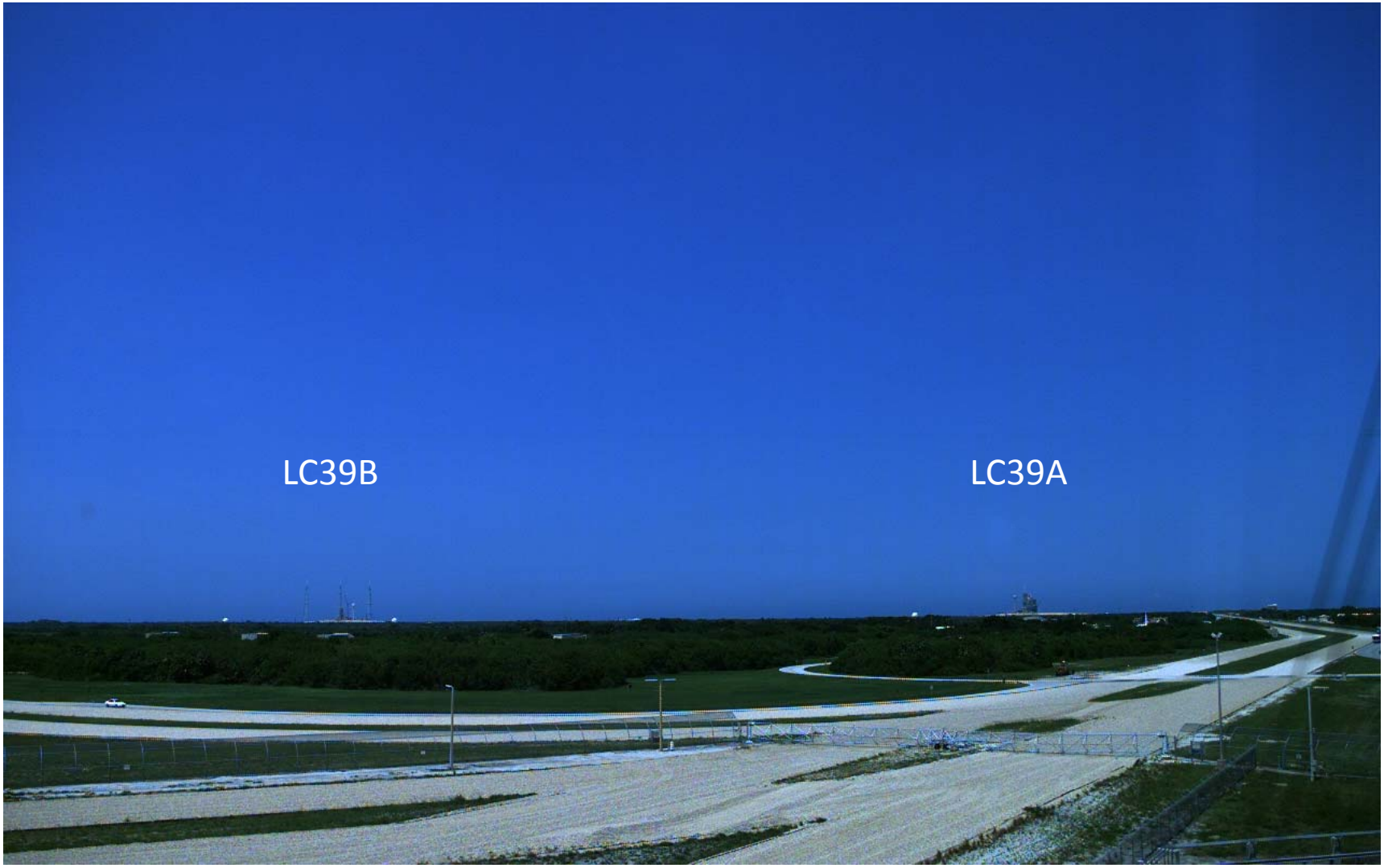
Bottom Camera:
Catenary (DC3 & DC4)



Top Camera:
Tower 2

LC39B LPS

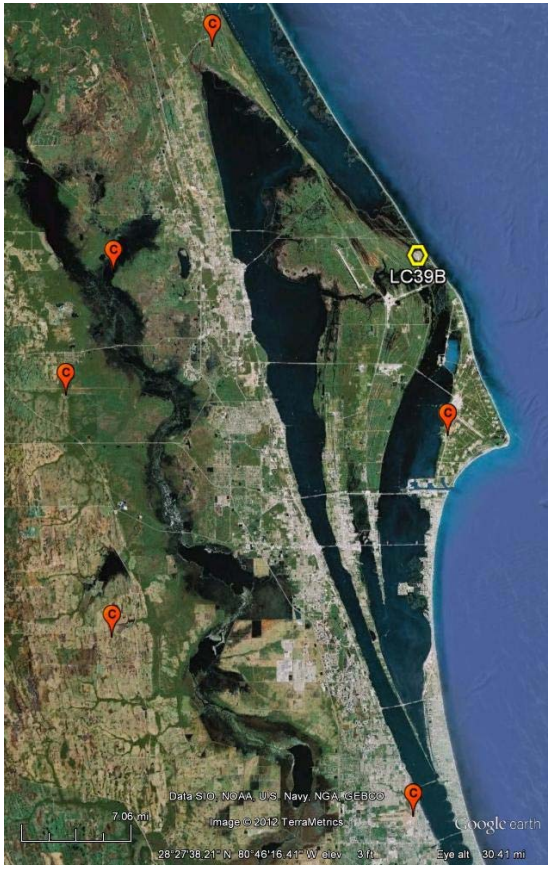
LCC Camera Field of View



KSC Lightning Location Systems

CGLSS II

Operational since summer of 1979
Effective range of about 100 km



6-sensor network (only 5 active since 2009)
Sensor baseline: about 30 kilometer

NLDN

Operational since early 80's
National coverage since late 80's

114-sensor network (15 sensors, Florida region)
Sensor baseline: 300-350 kilometer

3/31/2011 14:50:49.887 (UTC)

Direct Strike to DC 4

KSC LC39B LPS

1st RS of a 2-RS flash

I = -28.8 kA

10-90% RT = 2 us

Q_{1ms} = 2.88 C

Distance error [m]

CGLSS II	NLDN
-	409

Azimuth [degrees]

CGLSS II	NLDN
-	67

NLDN

I = -17.5 kA – Ground

5 sensors

5/27/2011 18:21:34.107 (UTC)

Direct Strike to Tower 2

KSC LC39B LPS

1st RS of a 2-RS flash (2nd RS was a nearby strike)

I = -77.6 kA

10-90% RT = 5.89 us

Q_{1ms} = 9.27 C

Distance error [m]

CGLSS II	NLDN
99	780

Azimuth [degrees]

CGLSS II	NLDN
52	261

CGLSS II

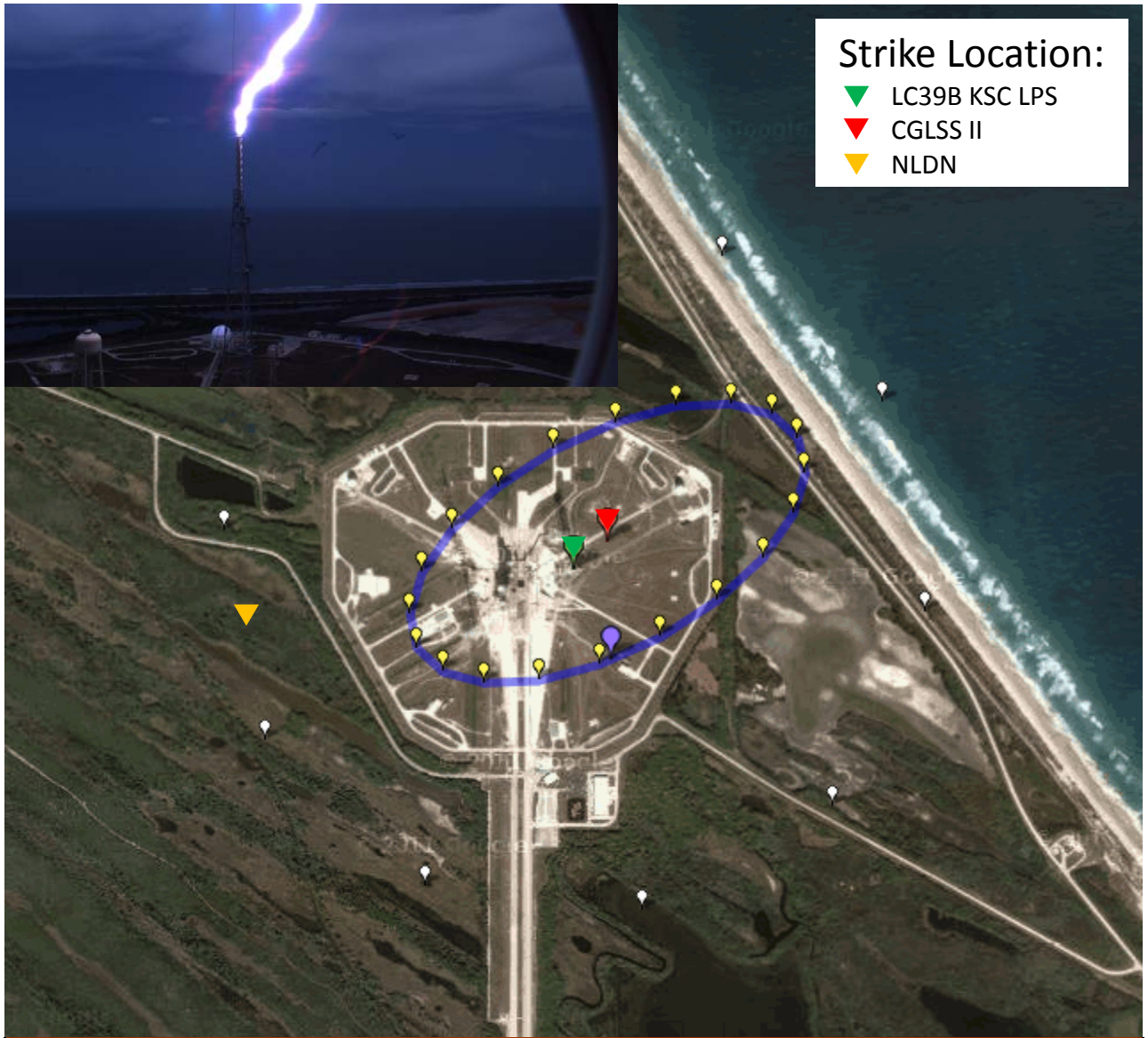
I = -57.0 kA (inside Ellipse)

5 sensors

NLDN

I = -63.8 kA – Ground

10 sensors



Date	Time	Azimuth Center	Range Center (nm)	Azimuth Closest	Range Closest (nm)	Magnitude (kAmps)	Target Inside Ellipse?	Sensors in Solution	Probability (radii of interest)	Difference (nm)	CG Stroke Latitude	CG Stroke Longitude	Semi-Major Axis (nm)	Semi-Minor Axis (nm)	Orientation Angle	Closest Point Latitude	Closest Point Longitude
05/27/2011	18:21:34.107	049	0.06	158	0.13	-57	Yes	5	99.999071%	-0.07	28.6281	-80.6188	0.28	0.14	60.80	28.6256	-80.6187

5/27/2011 18:25:47.633 (UTC)

Direct Strike to Tower 2 and simultaneous nearby strike

KSC LC39B LPS

Single-stroke flash

I = -26.4 kA

10-90% RT = 4.37 us

Q_{1ms} = 2.13 C

Distance error [m]

CGLSS II	NLDN
-	1,494

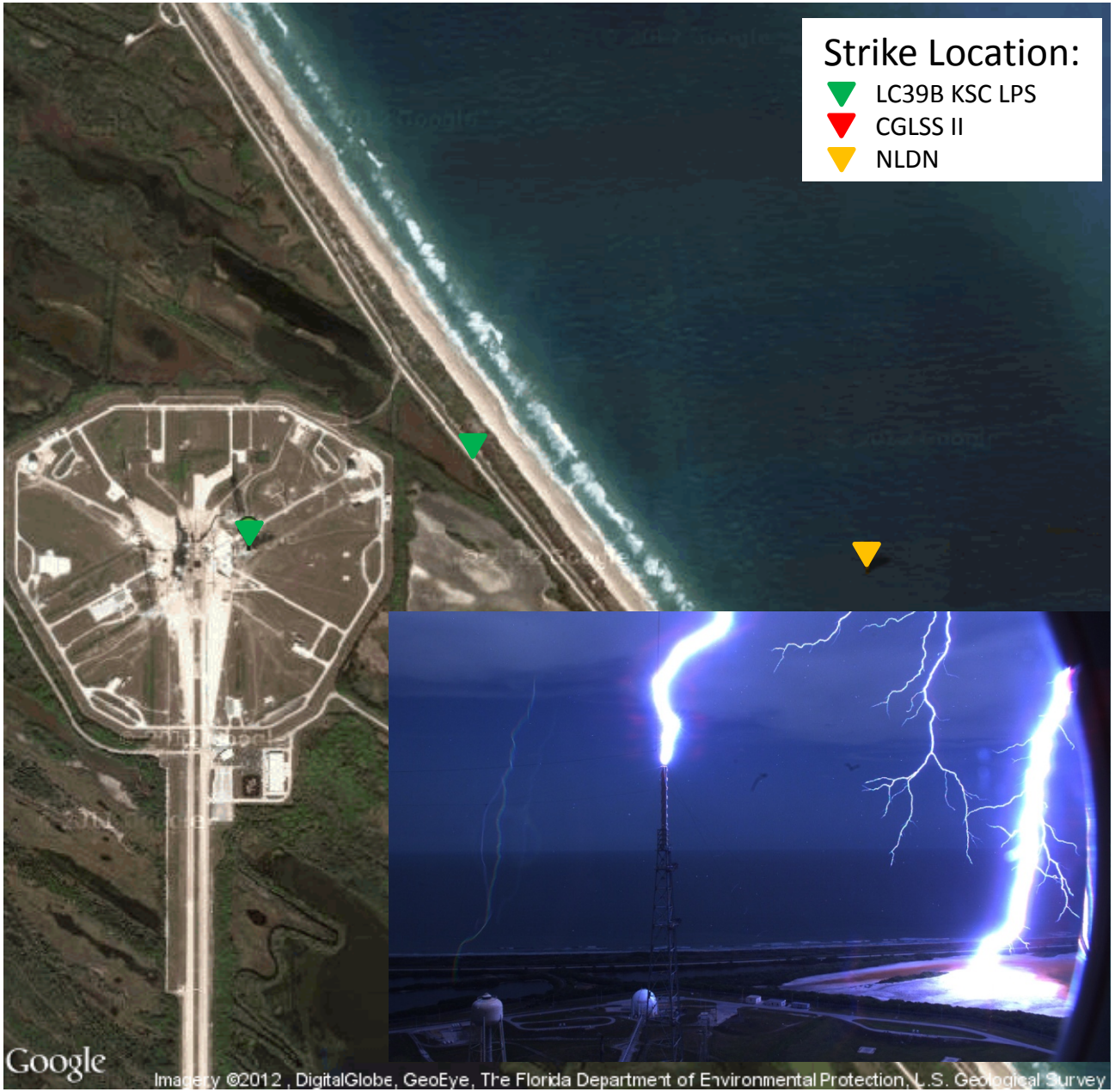
Azimuth [degrees]

CGLSS II	NLDN
-	92

NLDN

I = -33.8 kA – Cloud

10 sensors



6/15/2011 00:20:55.637 (UTC)

Direct Strike to DC 8

KSC LC39B LPS

Single-stroke flash

I = -29.4 kA

10-90% RT = 2.46 us

Q_{1ms} = 2.79 C

Distance error [m]

CGLSS II	NLDN
-	778

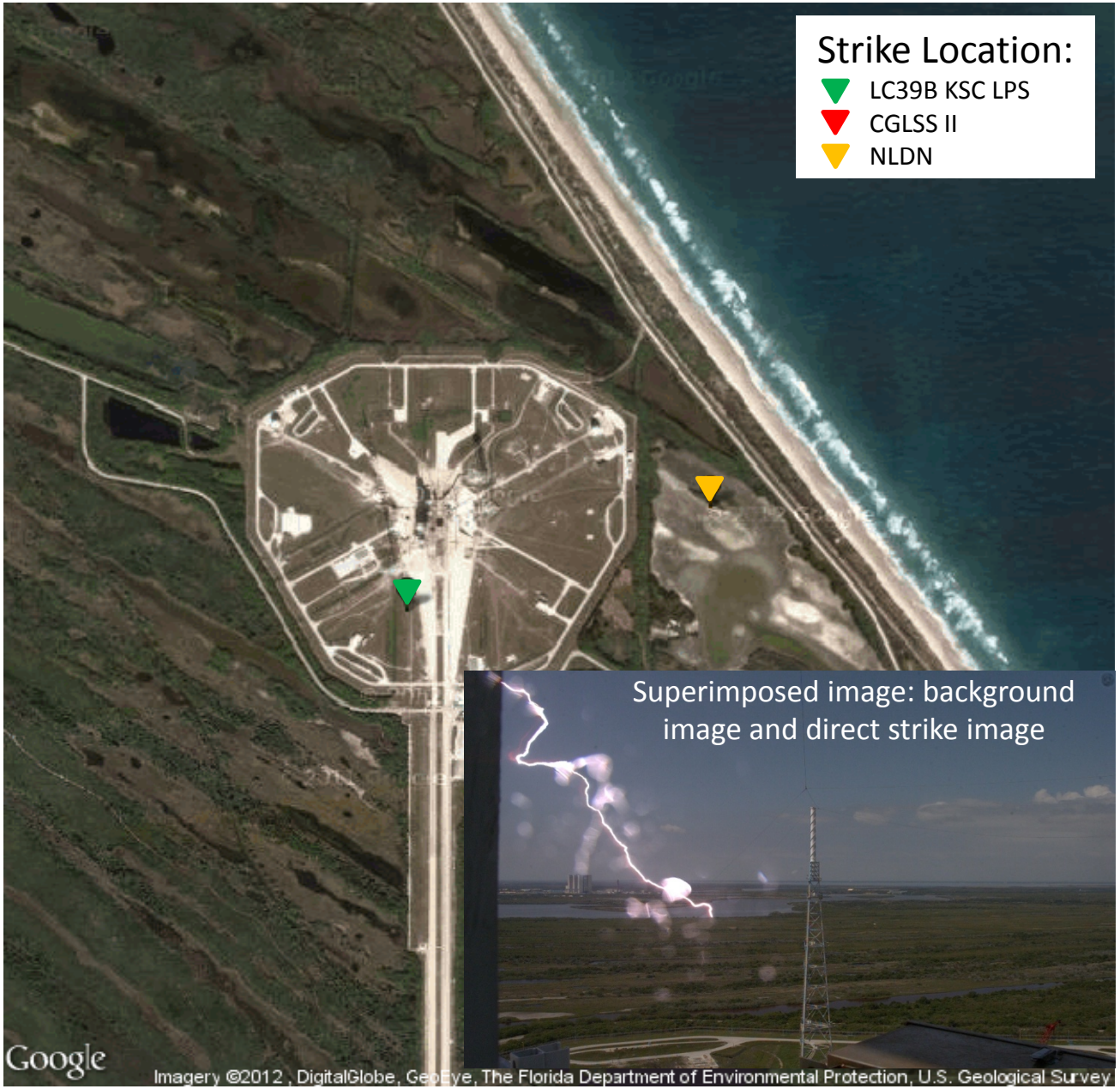
Azimuth [degrees]

CGLSS II	NLDN
-	71

NLDN

I = -16.8 kA – Cloud

6 sensors



7/07/2011 16:29:45.843 (UTC)

Direct Strike to Tower 3

KSC LC39B LPS

1st RS of a 3-RS flash (2nd RS simultaneous direct (T2) and nearby strike; 3rd RS was a nearby strike)

I = > -174.3 kA

10-90% RT = 5.41 us

Q_{1ms} = > 20.58 C

Distance error [m]

CGLSS II	NLDN
51	276

Azimuth [degrees]

CGLSS II	NLDN
139	171

CGLSS II

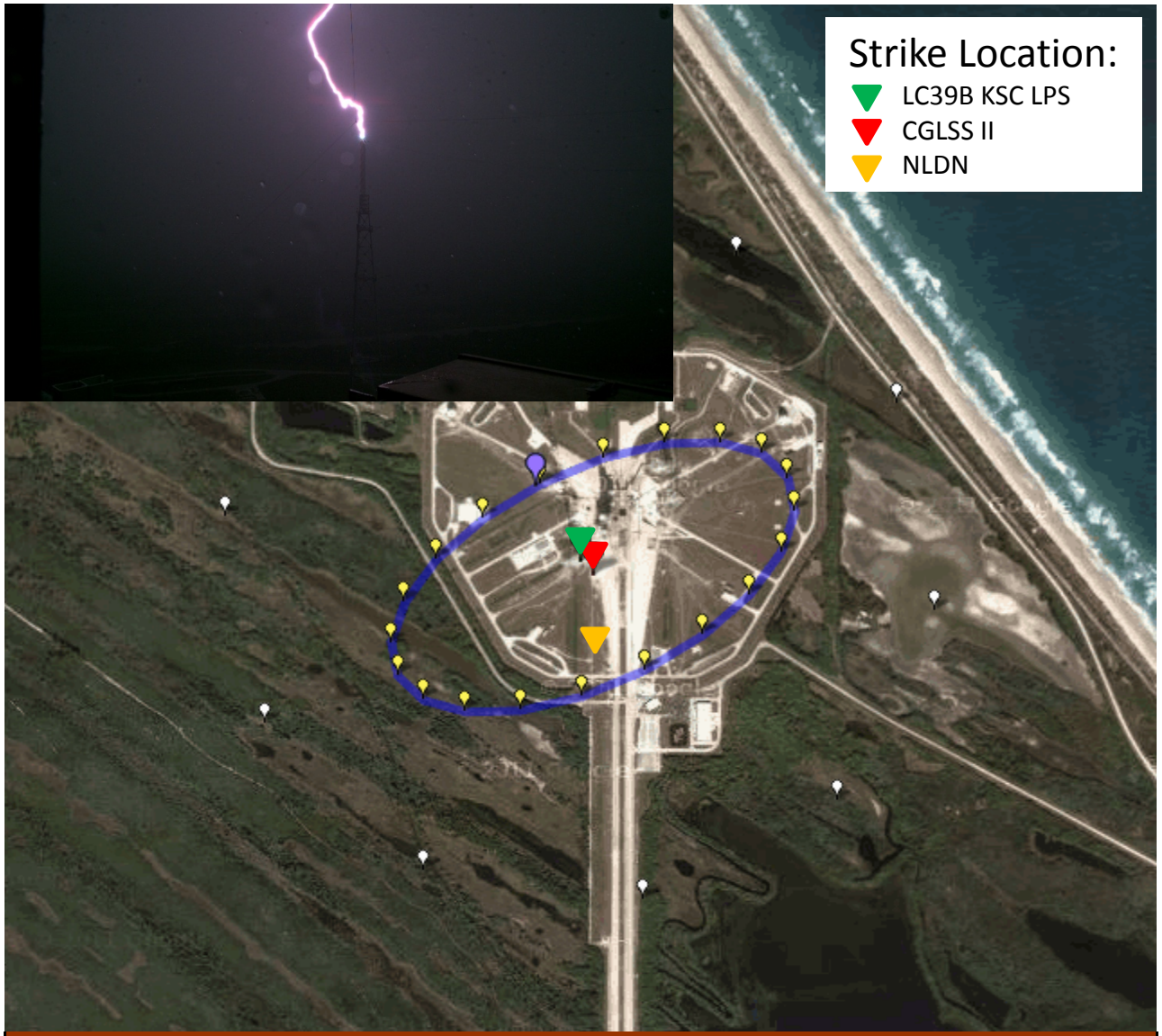
I = -141.5 kA (inside Ellipse)

5 sensors

NLDN

I = -157.2 kA – Ground

9 sensors



Date	Time	Azimuth Center	Range Center (nm)	Azimuth Closest	Range Closest (nm)	Magnitude (kAmps)	Target Inside Ellipse?	Sensors in Solution	Probability (radii of interest)	Difference (nm)	CG Stroke Latitude	CG Stroke Longitude	Semi-Major Axis (nm)	Semi-Minor Axis (nm)	Orientation Angle	Closest Point Latitude	Closest Point Longitude
07/07/2011	16:29:45.843	139	0.02	331	0.12	-141.5	Yes	5	99.999882%	-0.09	28.6258	-80.6216	0.28	0.14	62.00	28.6278	-80.6230

7/07/2011 16:29:45.931 (UTC)

Direct Strike to Tower 2 and simultaneous nearby strike

KSC LC39B LPS

2nd RS of a 3-RS flash

I = -65.7 kA

10-90% RT = 5.61 us

Q_{1ms} = 4.42 C

Distance error [m]

CGLSS II	NLDN
-	1,714

Azimuth [degrees]

CGLSS II	NLDN
-	114

NLDN

I = -125.1 kA – Ground

15 sensors

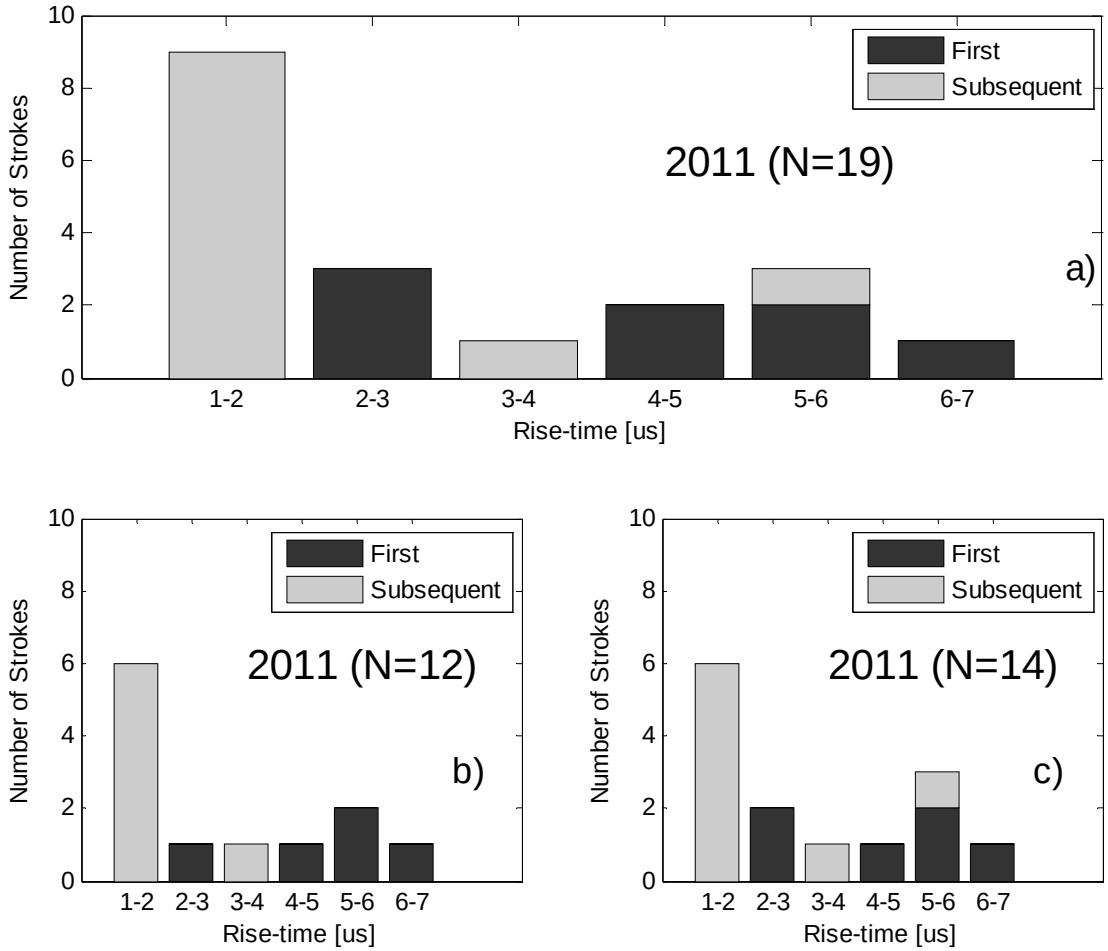
Stroke Detection Efficiency

Direct Return Strokes (March-December, 2011)	No. of Strokes	No. of NLDN Ground Strokes	NLDN Ground Stroke DE	No. of CGLSS II Strokes	CGLSS II Stroke DE
Total	19	14	74%	12	63%
First	8	6	75%	5	63%
Subsequent	11	8	73%	7	64%
Multiple simultaneous attachment points	2	1	50%	0	0%

- Strokes detected by LC39B LPS DAQ (Electromagnetic fields, current and/or video)
- There were two direct strokes identified by NLDN as Cloud discharges, both of them initially categorized as single-stroke flashes and one of them with multiple simultaneous attachment points.

LC39B LPS Direct Strikes
Current Rise-time (10%-90%) [us]

The rise-time was obtained from the LC39B LPS total calculated incident current

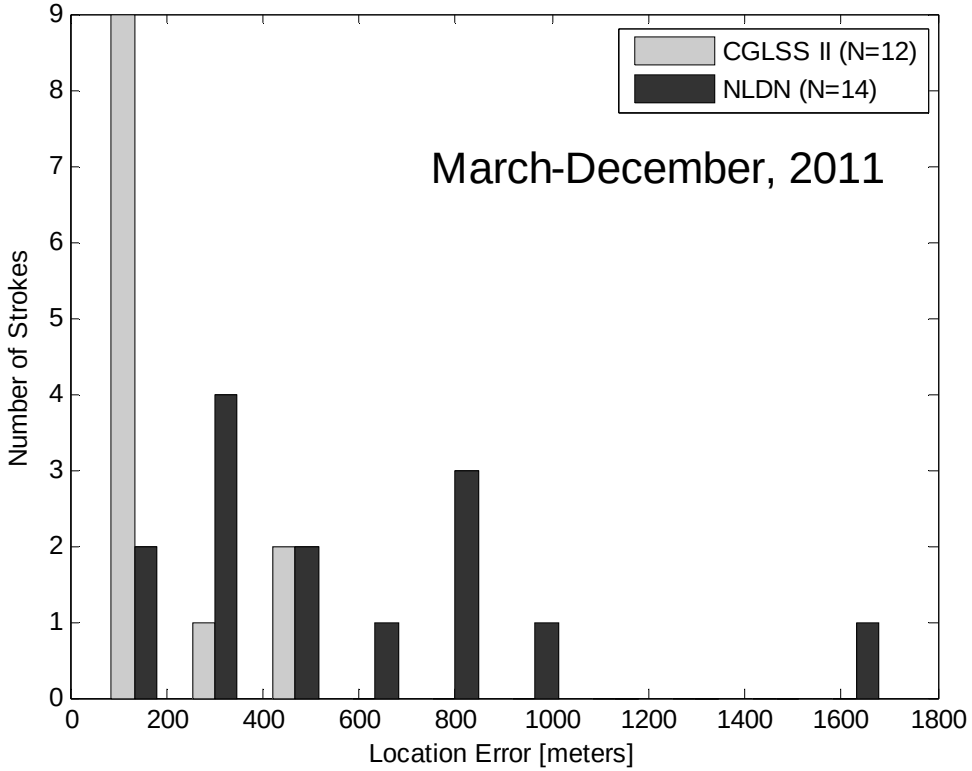


a) All return strokes attaching directly to the LC39B LPS

b) All direct strokes detected by CGLSS II

c) All Ground direct strokes detected by NLDN

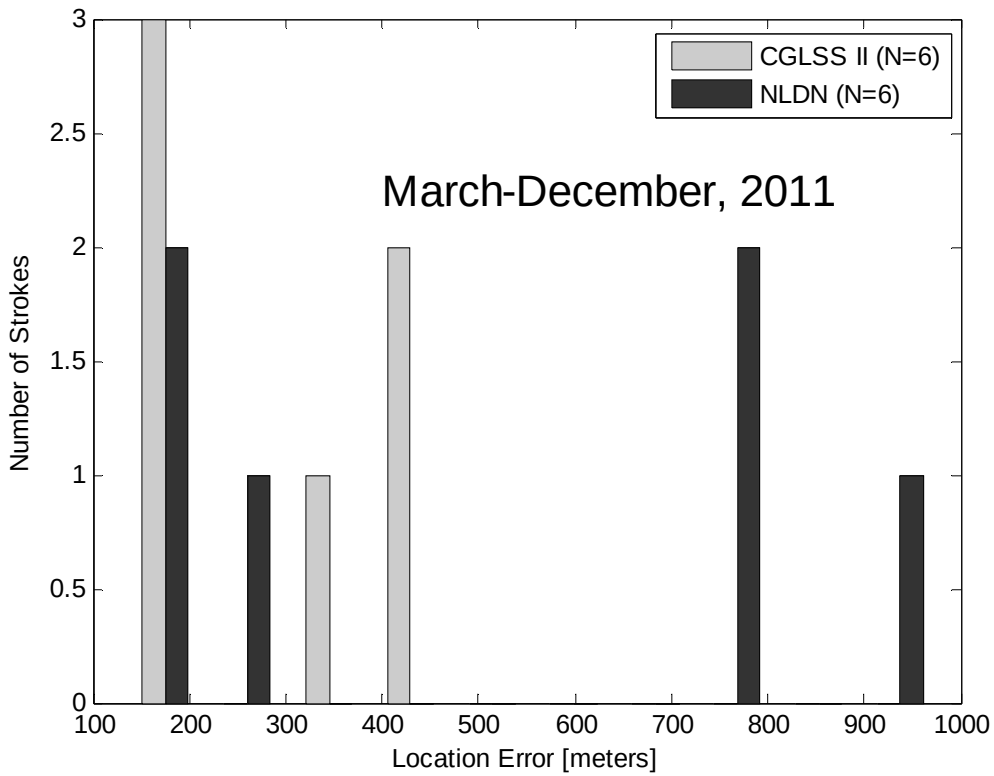
Location error [meters] per RS
All direct strokes



March December, 2011	NLDN	CGLSS
AM, m	572	190
SD, m	420	143
Median, m	405	155
Min, m	133	51
Max, m	1714	467
N	14	12

Histograms of absolute location errors for direct return strokes to LC39B LPS detected by CGLSS II (12) and NLDN (14). Statistics given are arithmetic mean (AM), standard deviation (SD) median, minimum, and maximum.

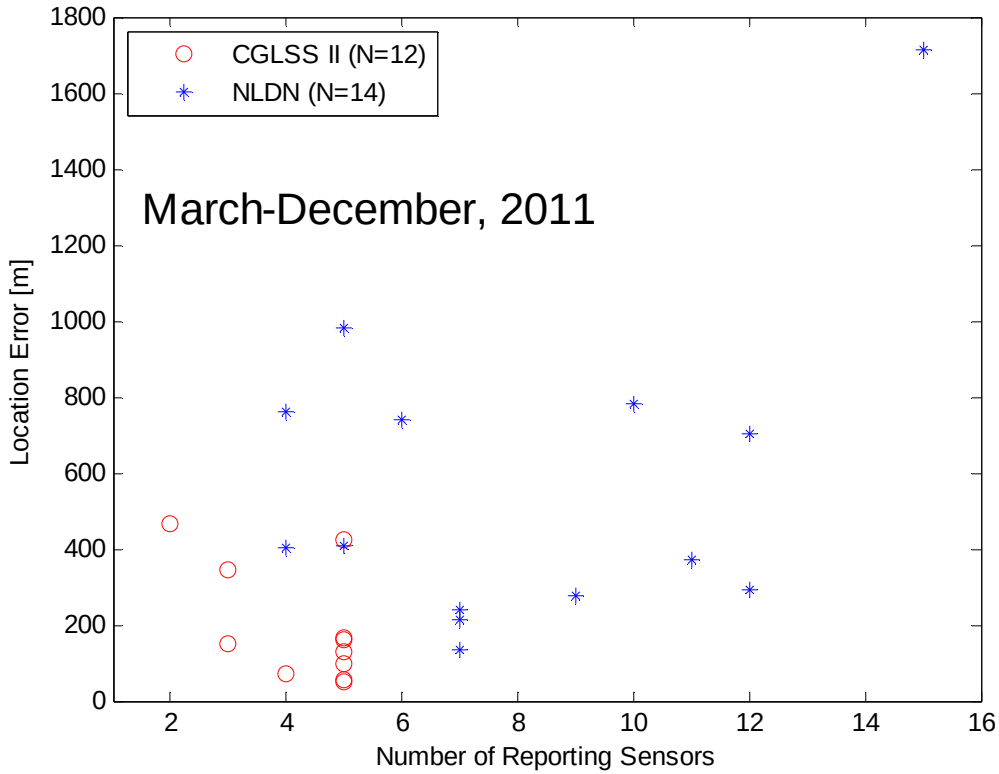
Location error [meters] per RS for all subsequent strokes following the same channel as the previous stroke



March December, 2011	NLDN	CGLSS
AM, m	510	287
SD, m	358	143
Median, m	487	256
Min, m	133	159
Max, m	980	467
N	6	6

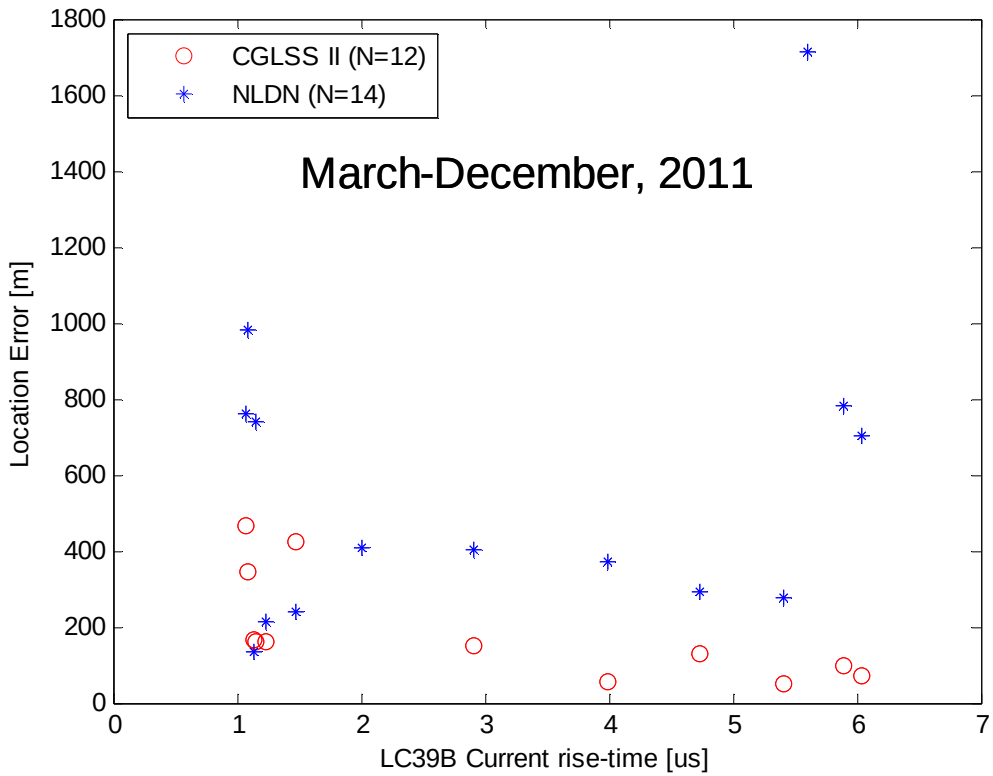
Histograms of absolute location errors for direct subsequent strokes to LC39B LPS following the same channel as its previous stroke and detected by CGLSS II (6) and NLDN (6). Statistics given are arithmetic mean (AM), standard deviation (SD) median, minimum, and maximum.

Location Error per Number of Reporting Sensors



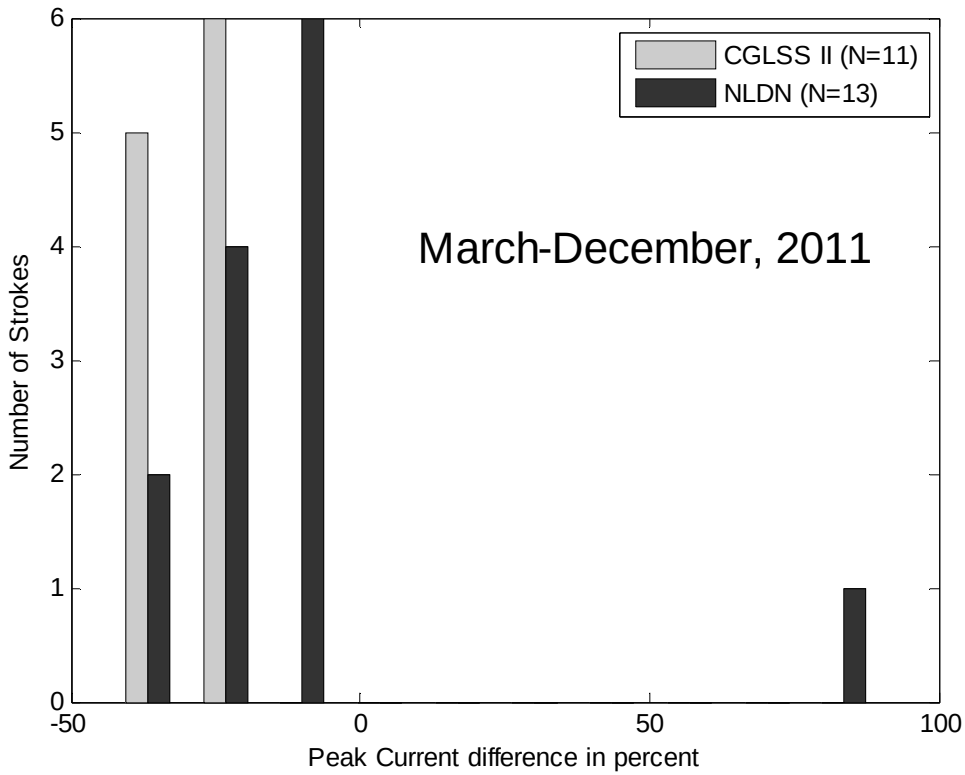
Absolute location error versus the number of reporting sensors for CGLSS II and NLDN.

Location Error per Current (LC39B) rise time (10%-90%)



Absolute location error versus the calculated rise-time (10%-90%) of the LC39B LPS calculated total incident current.

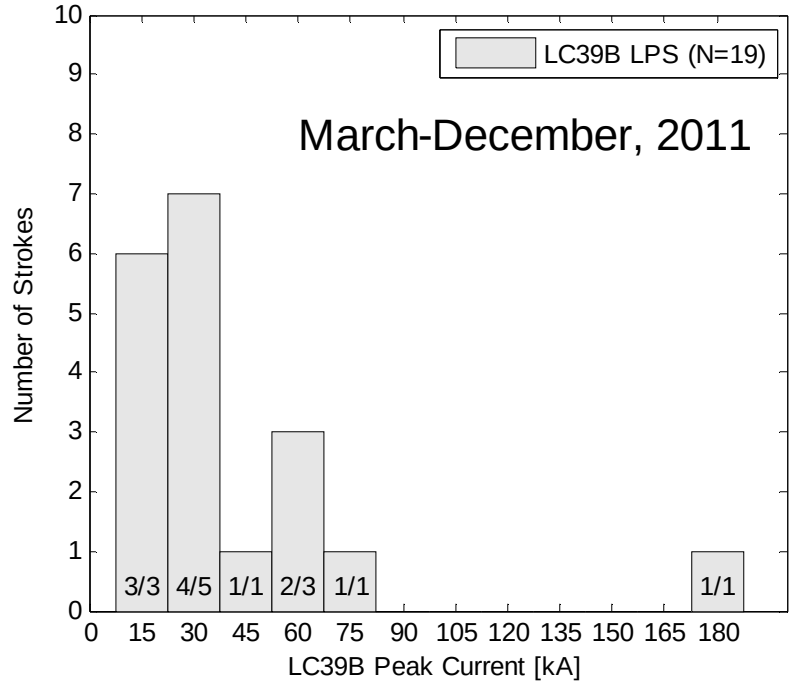
Peak Current difference in percent



Peak current difference in percent for both CGLSS II and NDLN reported peack currents using the LC39B LPS peak current (calculated total incident current) as reference. For one event NLDN shows a positive difference, this is due to that event having simultaneous multiple attaching points (tower 2 and nearby ground). Only 11 and 13 return strokes instead of 12 and 14 (CGLSS II and NLDN respectively) are included here due to LC39B LPS current saturation for one event.

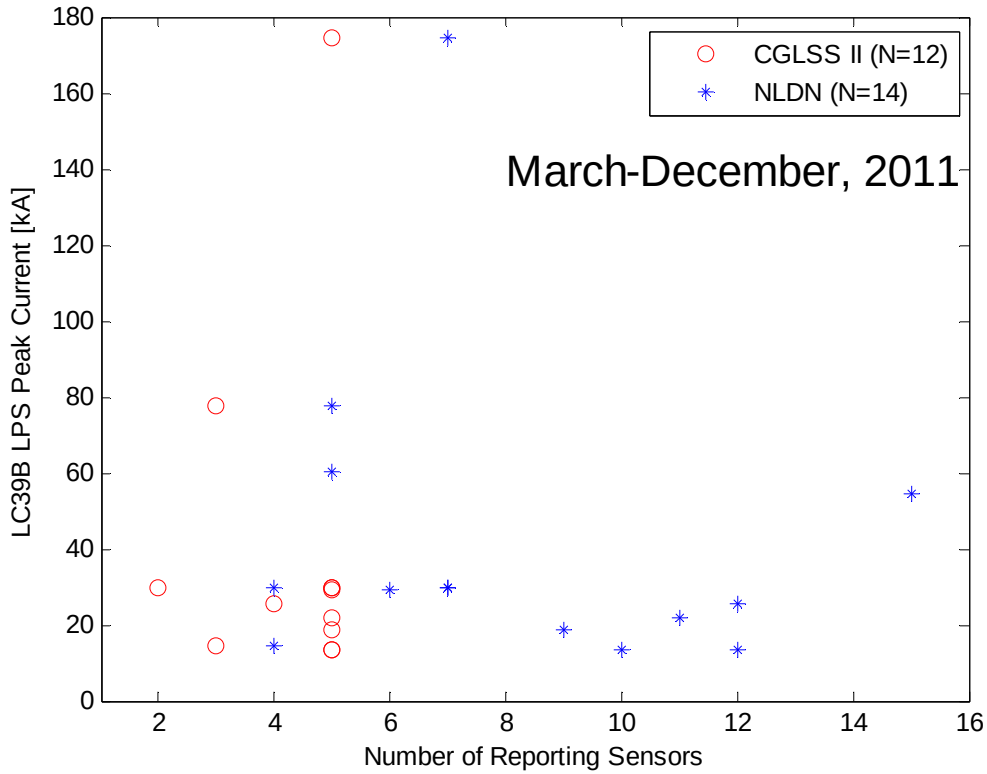
LC39B LPS Peak Currents.
The largest event recorded saturated (I > 174.3 kA)

All direct strokes detected (NLDN Ground RS)



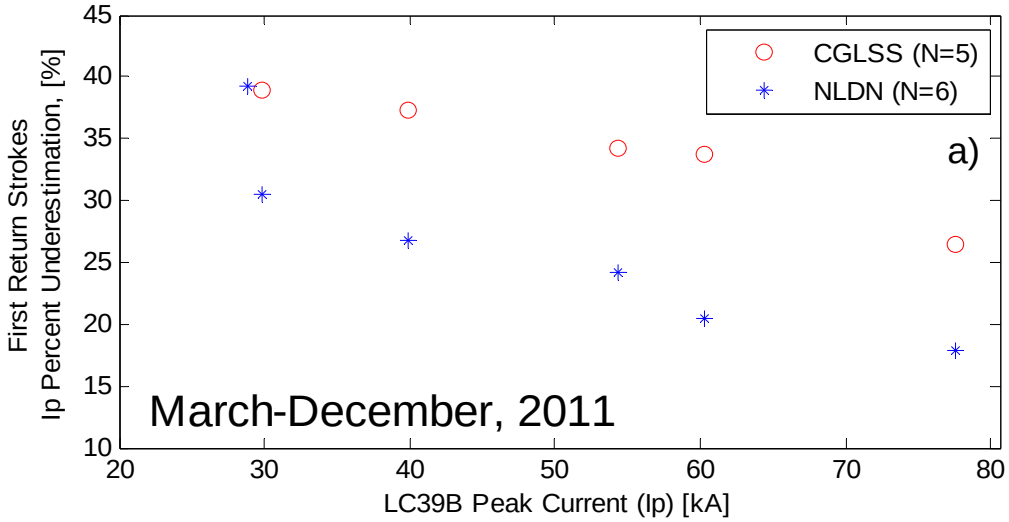
Detected strokes as a function of LC39B LPS Peak Current. For each peak current range (bin size of 15 kA) the ratio given inside the column indicates the number of strokes detected by CGLSS II (numerator) and NLDN (denominator) for that peak current range.

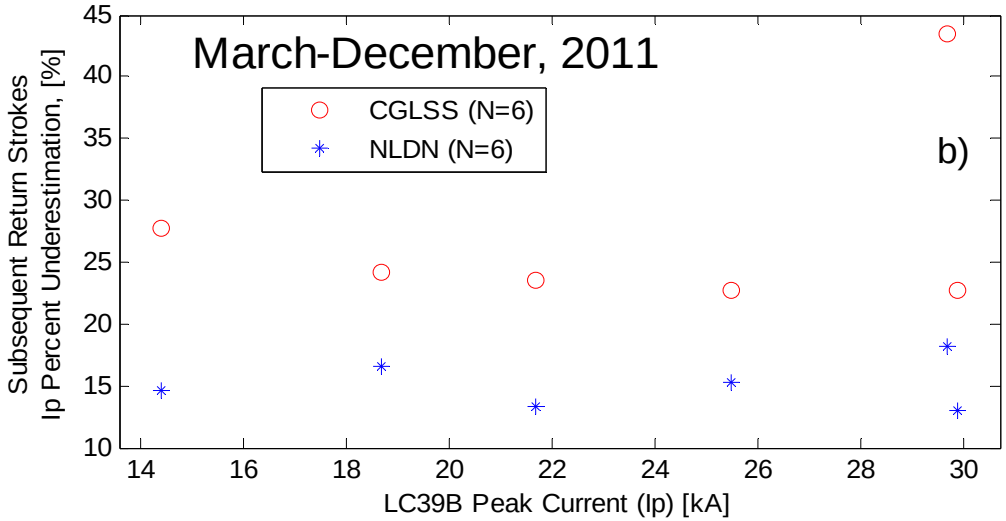
LC39B LPS Peak Currents.
The largest event recorded saturated (I > 174.3 kA)



LC39B LPS measured peak current (calculated total incident current) versus the number of sensors detecting that event for CGLSS II and NLDN.

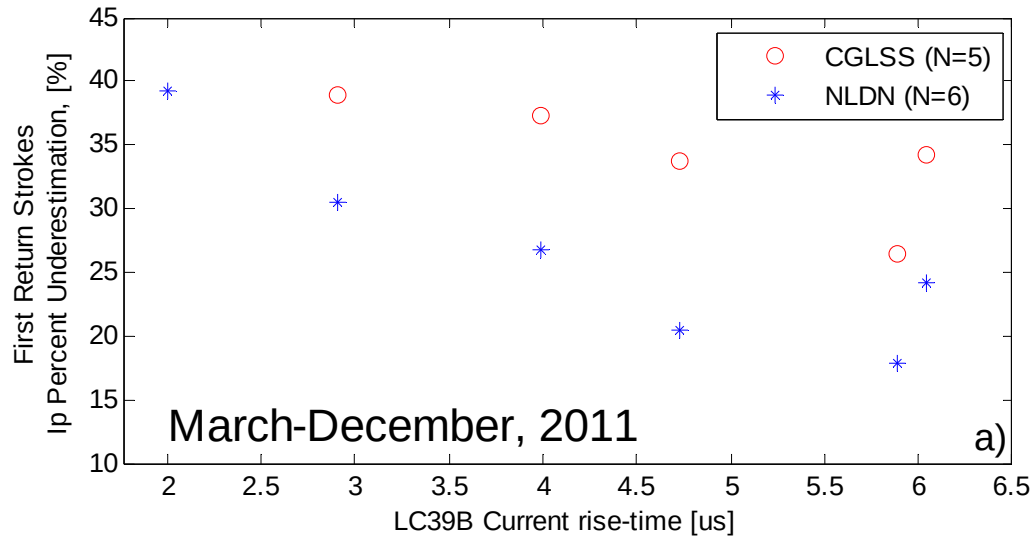
LC39B LPS Peak Currents.
The largest event recorded saturated (I > 174.3 kA)

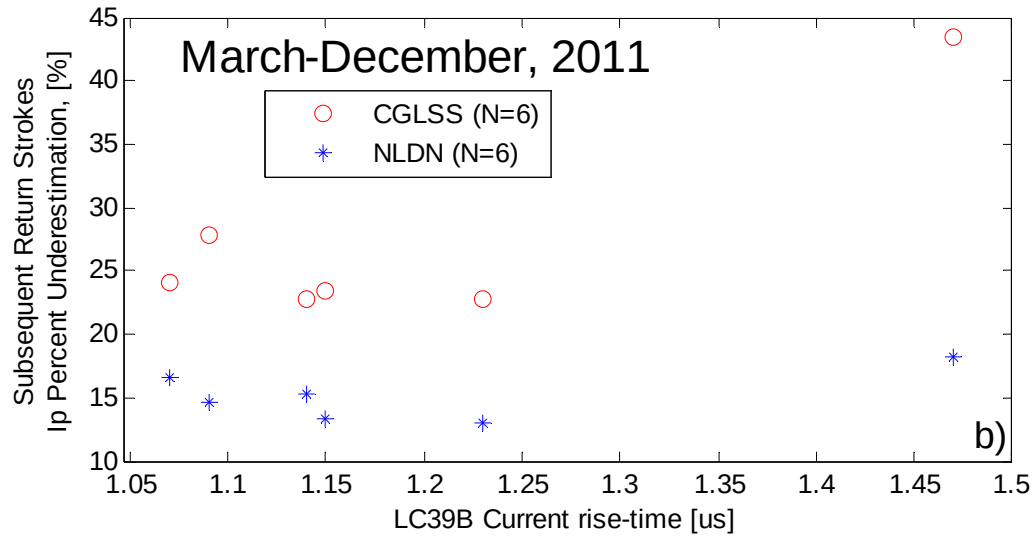




CGLSS II and NLDN peak current percent underestimation for selected direct return strokes to LC39B during 2011 based on LC39B LIS calculated peak current organized by a) first and b) subsequent return strokes.

LC39B LPS Peak Currents.
The largest event recorded saturated (I > 174.3 kA)





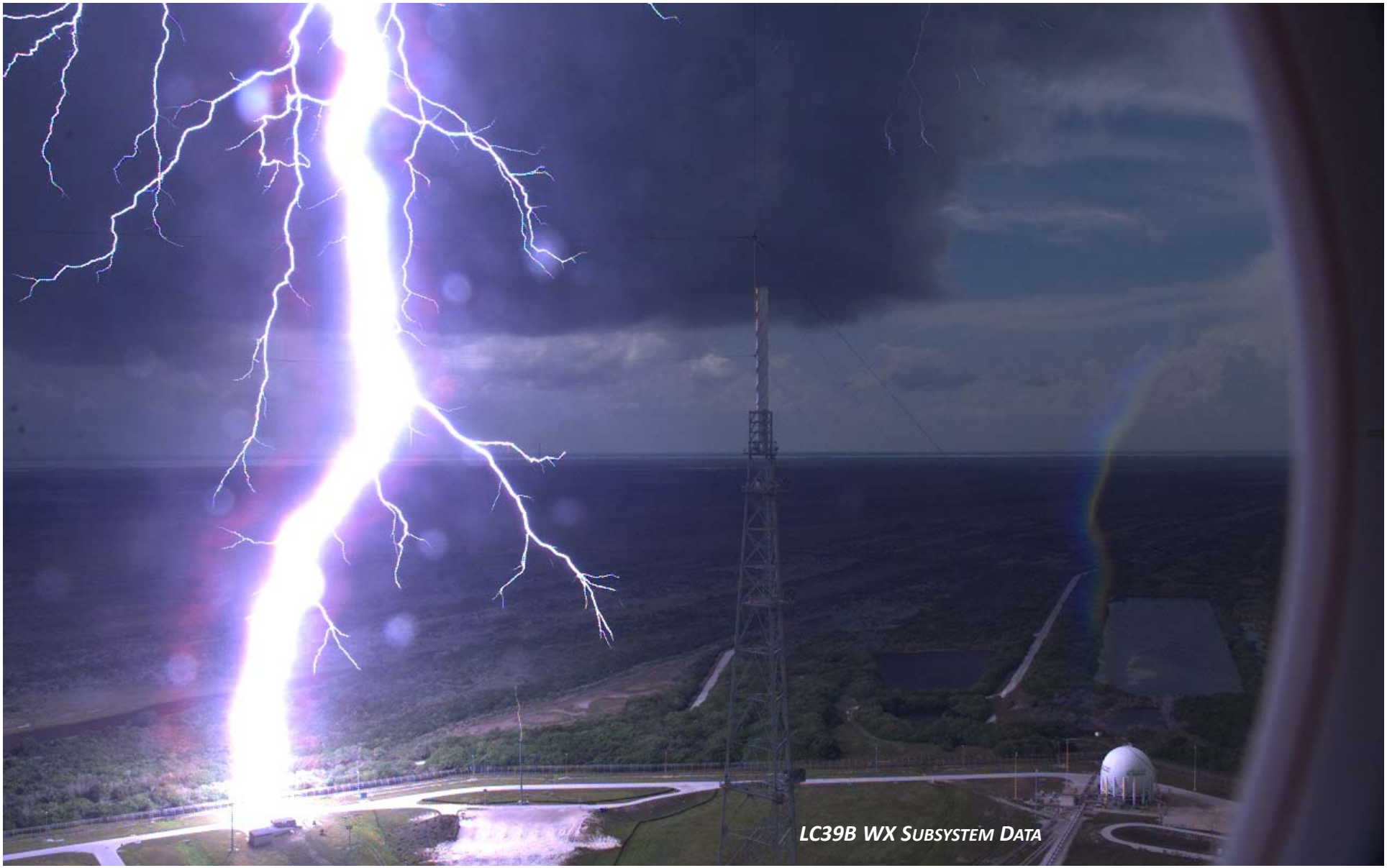
CGLSS II and NLDN peak current percent underestimation for selected direct return strokes to LC39B during 2011 based on LC39B LIS calculated 10%-90% current tise-time organized by a) first and b) subsequent return strokes.

Conclusions – LC39B LPS year 2011

- 19 direct strokes, stroke DE 63% and 74% for CGLSS II and NLDN, respectively.
- 70 neaby strokes, stroke DE 71% and 90% for CGLSS II and NLDN, respectively.
- 89 (19 direct and 70 nearby strokes), stroke DE 70% and 87% for CGLSS II and NLDN, respectively.
- CGLSS II and NLDN minimum, median, and maximum absolute location errors (in meters) for all detected direct strokes were 51, 155, 467 and 133, 405, 1,714, respectively.
- CGLSS II and NLDN minimum, median, and maximum absolute location errors (in meters) for all detected subsequent strokes following the same channel as the previous stroke were 159, 256, 467 and 133, 487, 980, respectively.
- Current underestimation of about -40 to -10% for both, CGLSS II and NLDN.
- One stroke (1 of 19) saturated two of the nine LC39B downconductor transient measurements at -174.3 kA (estimated to be a 200-220 kA negative stroke)
- Peak current median for 18 strokes is about -30 kA with rise-times between 1 and 6 microseconds and arithmetic mean of 2.9 microseconds.
- For 11 subsequent return strokes, the inter-stroke time intervals were between 23 and 180 milliseconds, with an arithmetic mean of 84 milliseconds.

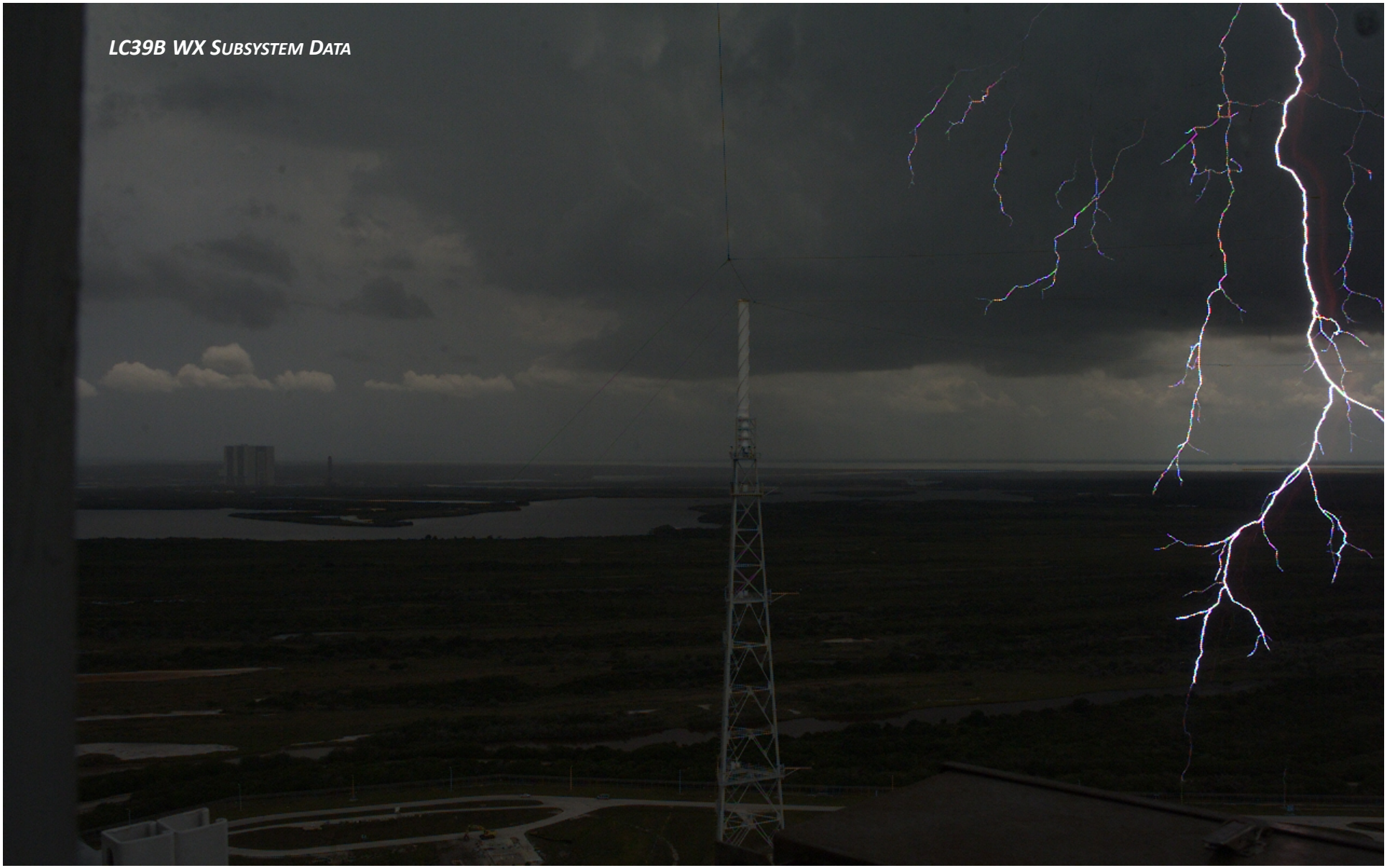
WX LC39B Salient Images

Direct Strike to LC39B Perimeter Fence – 5/27/2011



WX LC39B Salient Images

Upward Leader Visible, Direct Strike to LC39B Perimeter Fence – 5/27/2011

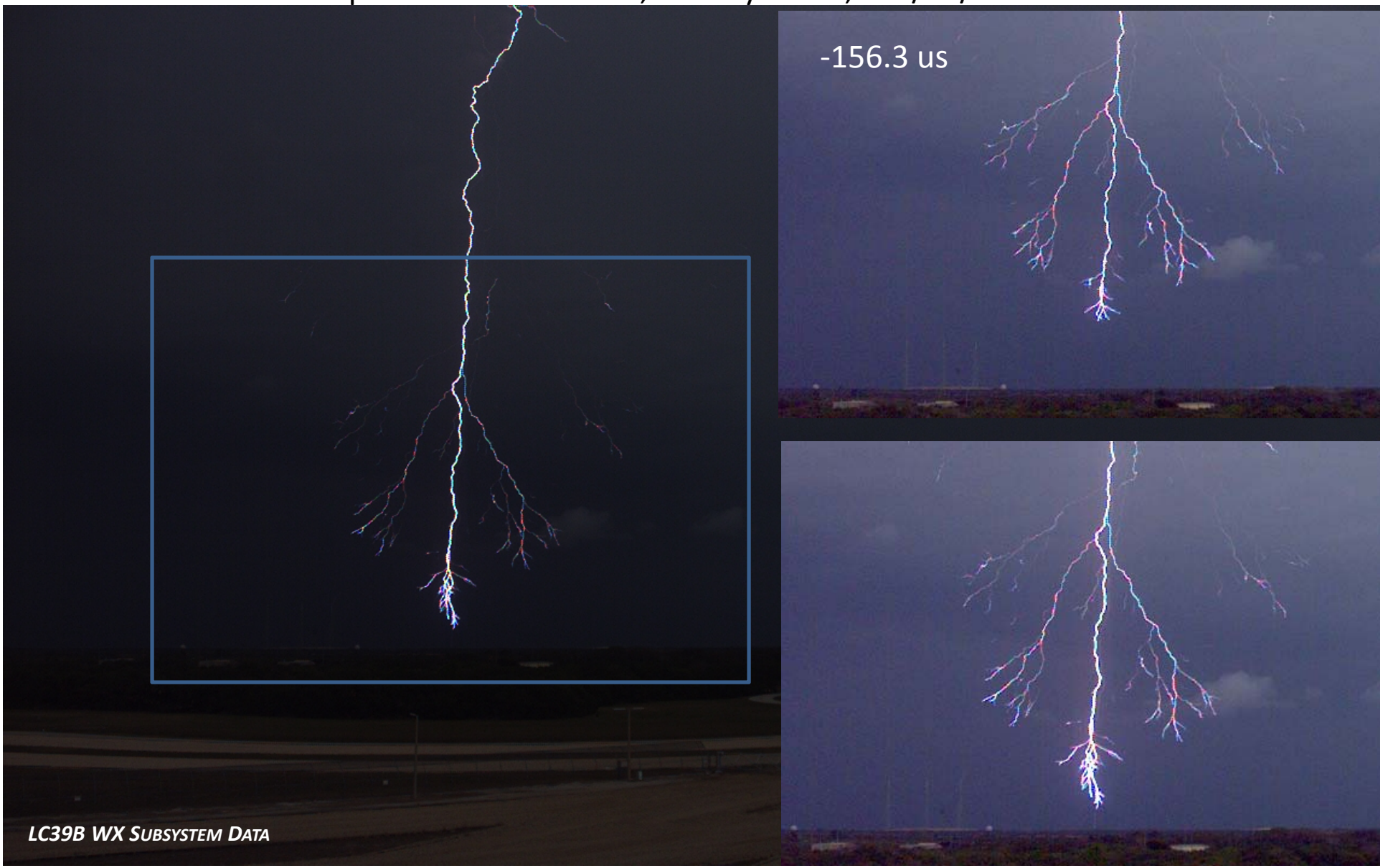


WX LC39B Salient Images

Two simultaneous attachment points – 5/27/2011

WX LC39B Salient Images

Upward Leader Visible, Nearby Strike, – 2/27/2012



Thank You

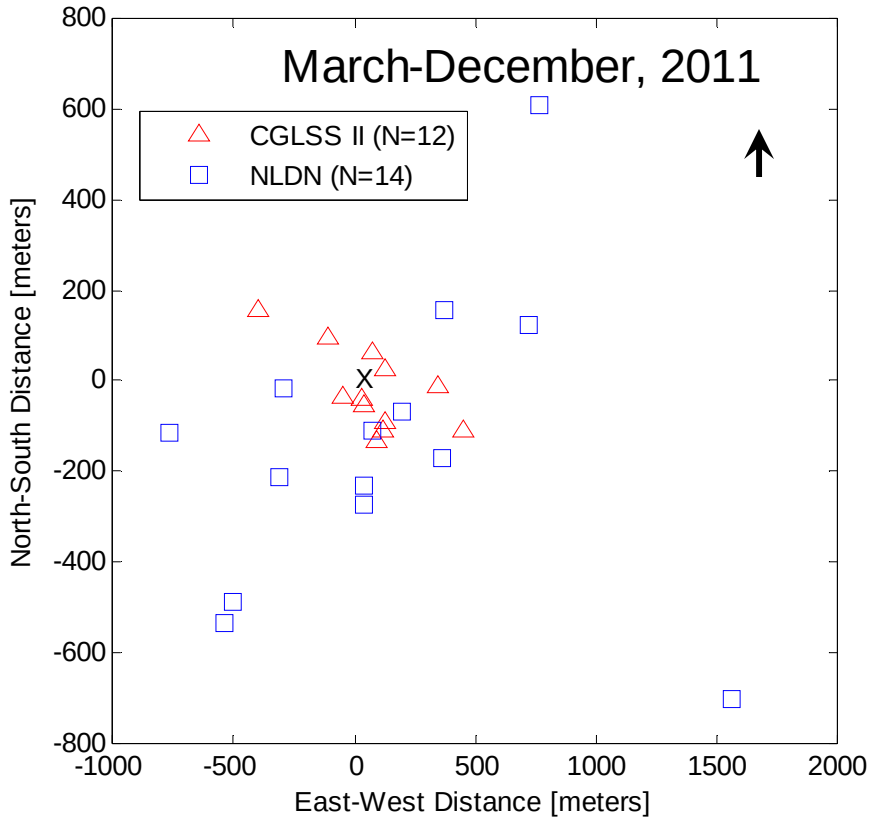
Backups

Stroke Detection Efficiency

Direct Return Strokes (March-December, 2011)	No. of Strokes	No. of NLDN Ground Strokes	NLDN Ground Stroke DE	No. of CGLSS II Strokes	CGLSS II Stroke DE
Total	19	14	74%	12	63%
First	8	6	75%	5	63%
Subsequent	11	8	73%	7	64%
Multiple simultaneous attachment points	2	1	50%	0	0%

- Strokes detected by LC39B LPS DAQ (Electromagnetic fields, current and/or video)
- There were two direct strokes NLDN identified by NLDN as Cloud discharges, both of them initially categorized as single-stroke flashes and one of them with a multiple simultaneous attachment points.

Distance errors (X-Y) in meters
All direct strokes

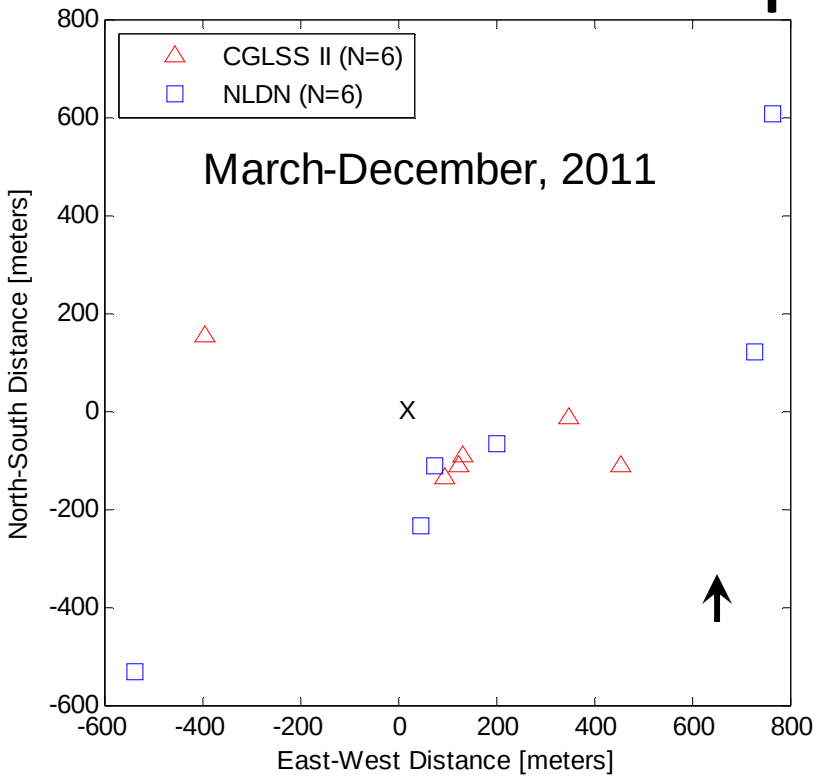


N-S and E-W Components of Location Error

March December, 2011		NLDN	CGLSS
N-S	AM, m	-145	-20
	SD, m	325	90
	Median, m	-143	-36
E-W	AM, m	124	73
	SD, m	619	213
	Median, m	58	85
N		14	12

Stroke location errors of detected CGLSS II (12) and NLDN (14) direct strikes to LC39B LPS. The origin is indicated by a cross and indicates the actual strike location. The horizontal axis corresponds to the east-west component of the location error (positive values correspond to the east). The vertical axis corresponds to the north-south component of the location error (positive values correspond to the north). The arrow indicates the north. Statistics given are arithmetic mean (AM), standard deviation (SD), and median.

Distance errors (X-Y) in meters for all subsequent strokes following the same channel as the previous stroke



N-S and E-W Components of Location Error

March December, 2011		NLDN	CGLSS
N-S	AM, m	-35	-50
	SD, m	384	109
	Median, m	-89	-100
E-W	AM, m	211	125
	SD, m	488	293
	Median, m	136	127
N		6	6

Stroke location errors of subsequent strokes following the same channel as its previous stroke and detected by CGLSS II (6) and NLDN (6). All these strokes attached directly to the LC39B LPS. The origin is indicated by a cross and indicates the actual strike location. The horizontal axis corresponds to the east-west component of the location error (positive values correspond to the east). The vertical axis corresponds to the north-south component of the location error (positive values correspond to the north). The arrow indicates the north. Statistics given are arithmetic mean (AM), standard deviation (SD), and median.

2011 Direct Strikes to LC39B LPS

Direct Stroke to LC39B LPS	Color Code
Detected	
Detected Nearby	
NLDN Cloud Discharge	
Additional Strokes Reported by CGLSS and/or NLDN	
Not Detected (CGLSS/NLDN)	

Day	LC 39B LPS Lightning Instrumentation			CGLSS	NLDN
	Flash	RS	Location		
3/31	1	1	DC 4		
		2	DC 3 (cat)		
5/27	2	1	T2		
		2	Nearby		
	3				
		1	DC8		
	4				
		1	T2 & Nearby		
6/15	5	1	DC8		

2011 Direct Strikes to LC39B LPS

Direct Stroke to LC39B LPS	Color Code
Detected	
Detected Nearby	
NLDN Cloud Discharge	
Additional Strokes Reported by CGLSS and/or NLDN	
Not Detected (CGLSS/NLDN)	

Day	LC 39B LPS Lightning Instrumentation			CGLSS	NLDN
	Flash	RS	Location		
7/07	6	1	T3		
		2	T2 & nearby		
		3	Nearby		
	7	1	T2		
		2	T1		
		3	T1		
		4	T1		
		5	T1		
		6	T1		
		7	T1		
		8	T1		
8/14	8				
		1	T1		
		2	T1		
		3	T1		