GLM Performance Assessment Using Ground-based Lightning Network Data

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with help from:

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LI/GLM Workshop 2015

Topics

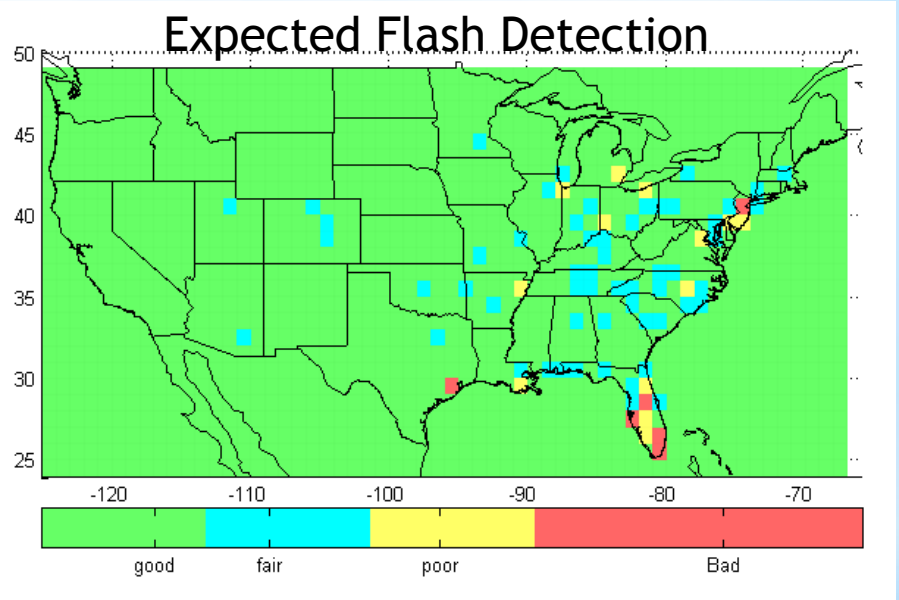
- Proposed GLM Verification Approach *(beyond the instrument…)*
  - Hierarchical assessment of RTEPS=>Regions => GLM pixels
    - Location Accuracy using CG strokes
    - "Strokes" => GLM group DE
    - Channel mapping => GLM spatial extent
  - Continuous, recursive statistics
  - Findings used to initiate lower-level assessment (deep dive)
  - Choice of reference network(s) depends on both availability and applicability
    - Must also maintain current performance statistics
      - Multi-network
      - Self-referenced

- Tools (thus far)
  - 2-Network Inter-comparison
    - Un-attended use (batch)
    - LA,DE, Type classification, field/current calibration
    - DE Analysis Options
      - Stroke and flash
      - Spatial Map, and overall avg.
    - CHUVA Examples
  - 3-network DE
    - Multiple 2-network analyses

  - Multi-system Exploration
    - LIS Groups, LMA, And LF networks
    - Interactive use
    - Time-height
    - Spatial plan view

Data-driven Performance Assessment

- Analysis Resolution
  - Depend on viewing domain
  - Statistical aggregation of lower-level (single pixel) statistics
- Possible Realizations
  - Dedicated mapping tool
  - Overlay placed over any data map
    - Enable/Disable
    - Adjustable transparency



* Performance Metrics and Reference datasets

Performance Parameter	Preferred Reference	"Good" Values	"Poor" Values	Comments
Location Accuracy	CG Return Strokes	1 nearest neighbor?	>1 nearest Neighbor > 50% of the time	Brightest or closest event in +/- 2 ms (?)
Group/CG Detection Eff.	>80% CG Stroke DE VLF/LF Network	>60%	< 50%	Lower-performance networks could be used with modified performance thresholds
TL Flash Detection. Eff. (required?)	>80% cloud Flash DE	>60%	< 50%	Lower-performance networks can be used with modified performance thresholds
Per-minute Spatial Extent (desired)	VLF or LF Mapping systems	>xx% of flash area	< yy% of flash area	LF system will need to be able to map horizontal channels in extensive flashes

Can we agree that CG strokes are as hard to detect as anything?

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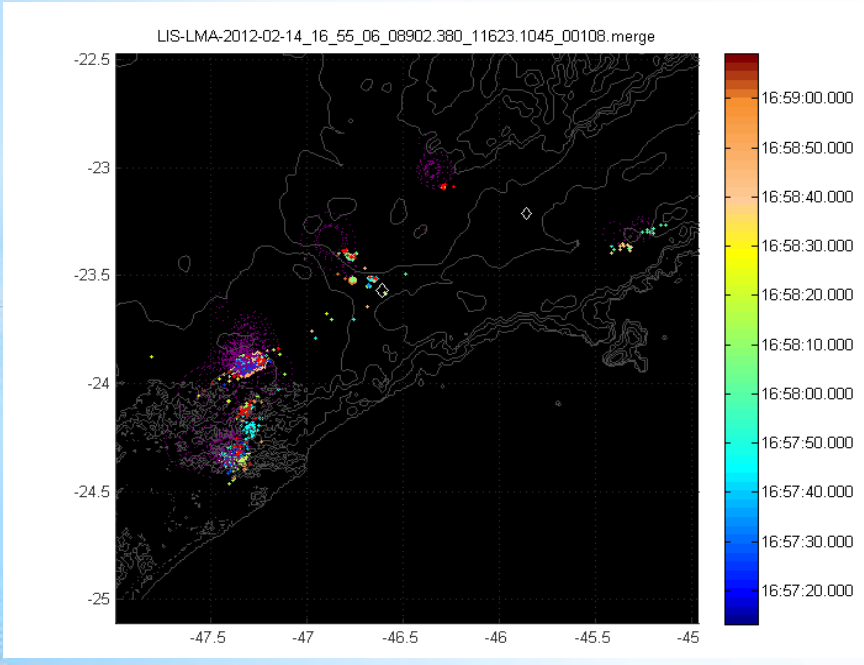
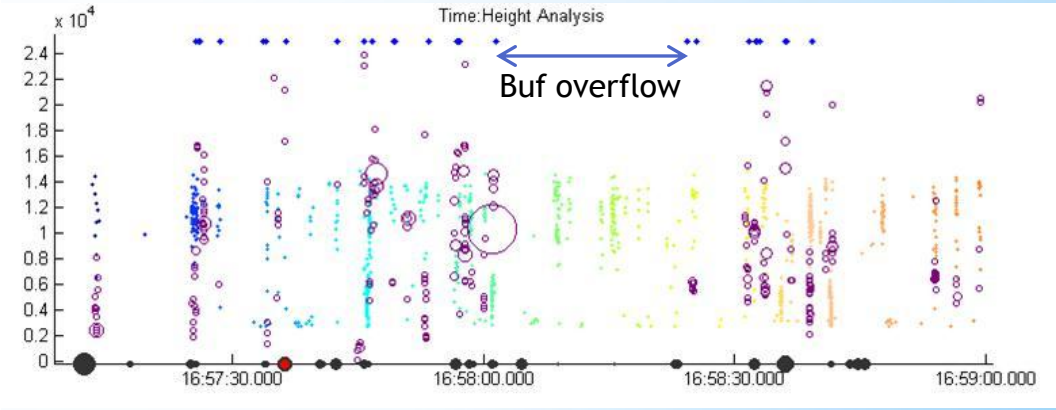
LIS Group Exploration Tool
Example: LIS, SPLMA, and TLS-CG

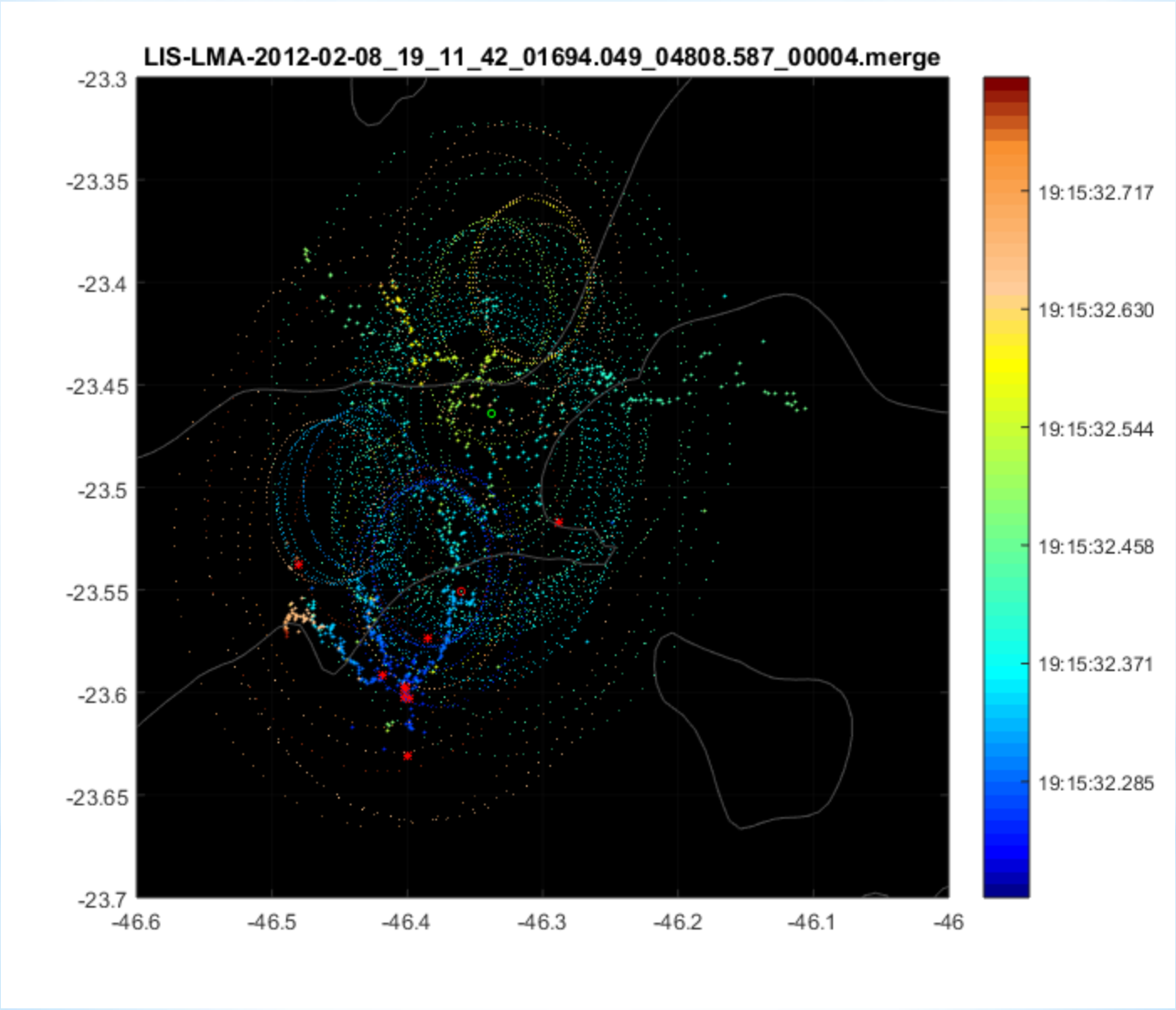
- Spatial Analysis
  - Limited to LIS swath coverage for each second
  - LIS Groups: Magenta circles w/ area = LIS group area
  - LMA: sources color-coded by time
  - TLS-CG: red "dots"



- Time:Height Analysis
  - LIS Groups:
    - area ∝ to radiance
    - "Height" ∝ distance from 7 closest LMA sources
  - LMA: same "time" color scale as spatial analysis
  - TLS-CG
    - Area ∝ peak current
    - Black: negative
    - Red: positive

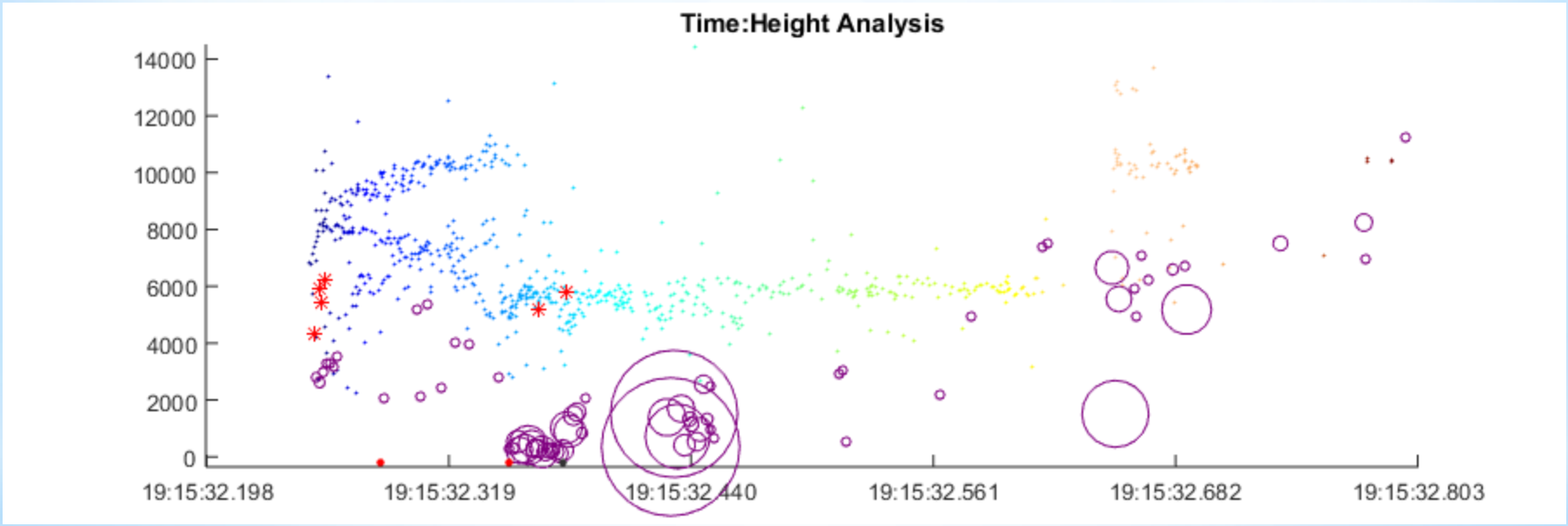


Spatial Analysis – single flash for LIS Groups, LINET, and LMA

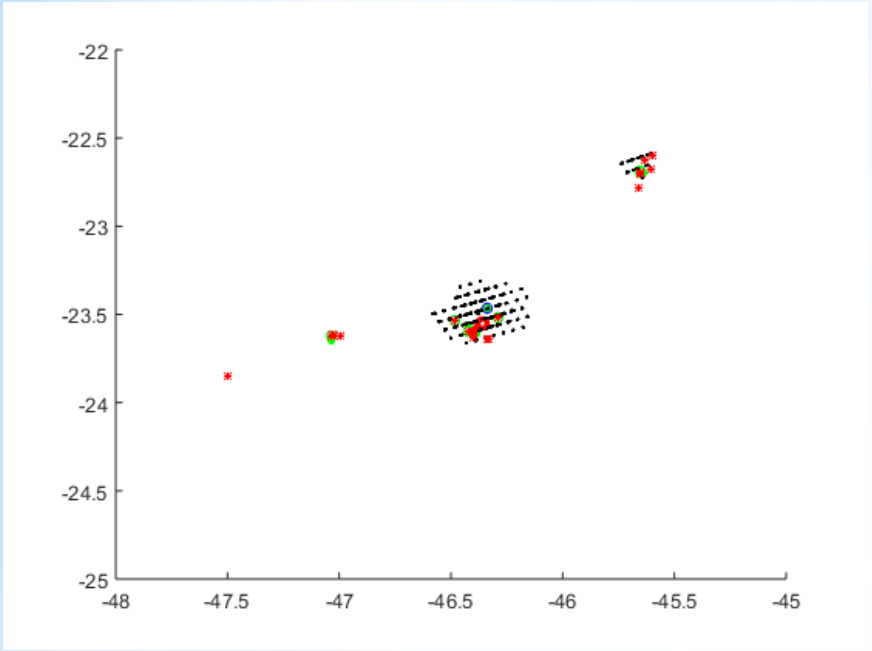


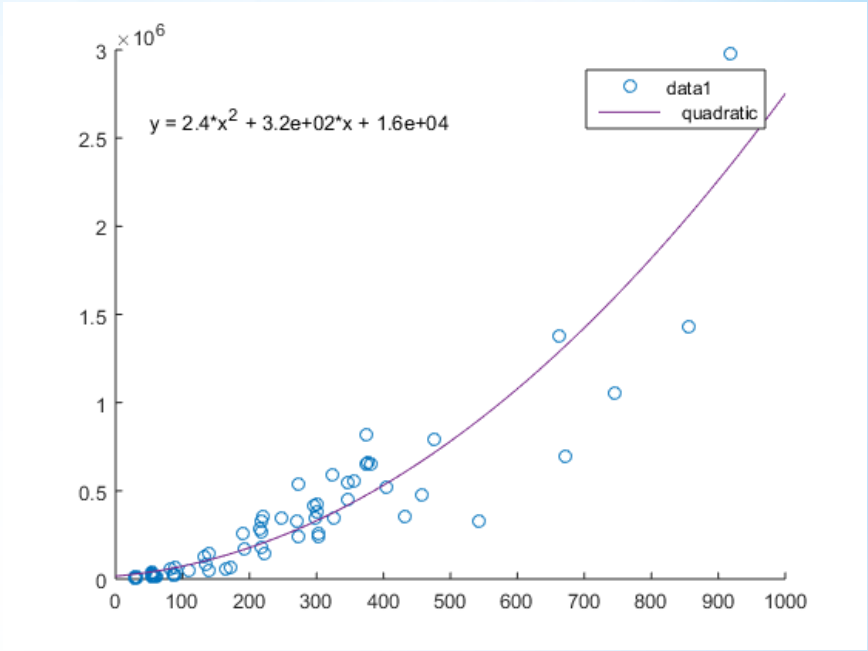
*Temporal Analysis – single flash got LIS Groups, LINET, and LMA

(no consistent relationships with LIS, other than occurrence time)



Spatial Analysis Examples – what correlates?





Generally reasonable spatial correlation between LF stroke/pulses and some of the LIS Events constituting a group

LIS Group Area and "accumulated" Group Radiance have reasonable correlation

LLS Inter-comparison Tool

* Coded in Matlab
* Stand-alone executables can run on 64-bit Linux & Windows
* Can specify datasets and related parameters in a "cfg" file using a text editor…

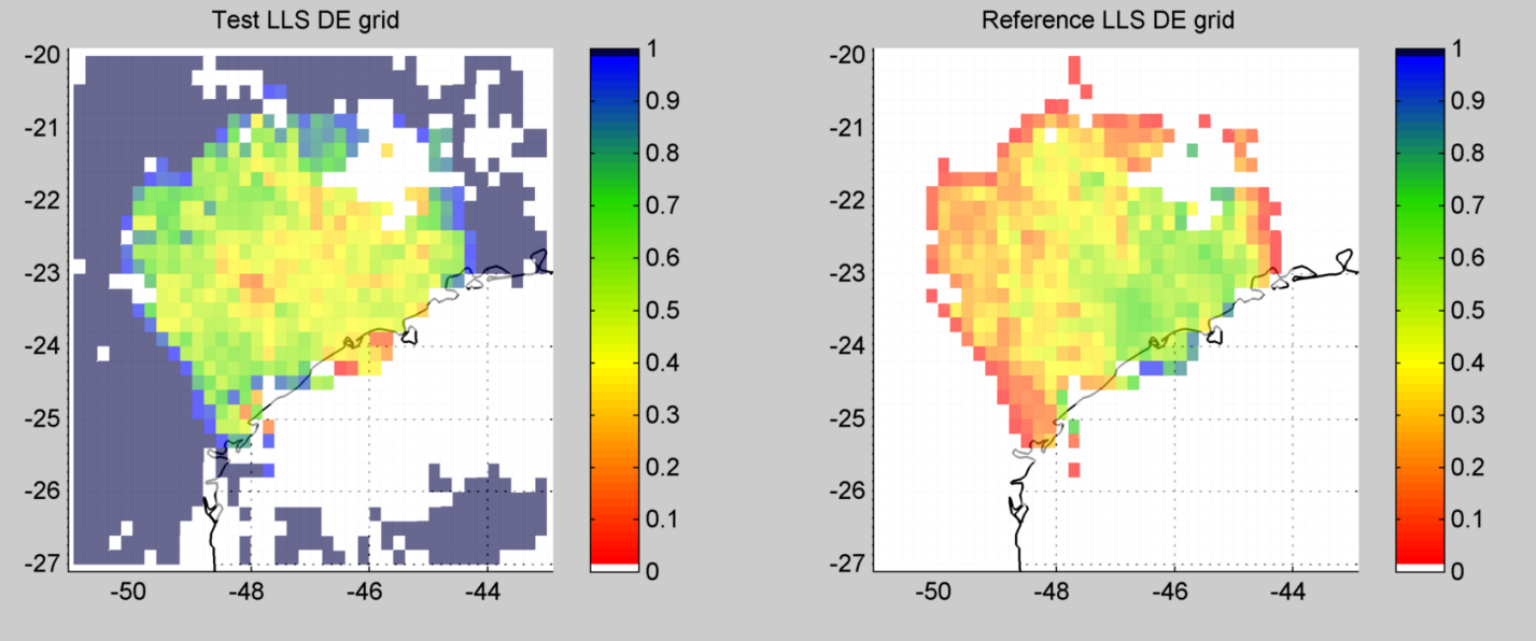
```
# sample Spec file for LLS comparison
# written by Ken Cummins,  July 2011

# Definition of possible fields in each data file
#    Date (D): date yyyy-mm-dd
#    Time (O): Occurrence time (hh:mm:ss.mmmmmm)
#    Lat (L): decimal degrees
#    Lon (G): decimal degrees
#    Ip (I): Peak Current (kA)
#    LocErr (E): position error (km)
#    ChiSq (C): Chi-square or consistency parameter
#    NSR (N): integer number of sensors reports
#    Type (T): G or C
#    Skip (S): field to skip
#

Ref_file: data/sampleRef.asc
Ref_fmt: DOLGIECTN

Test_file: data/sampleTest.asc
Ref_fmt: DOLGIECTN

# DT is the nominal correlation time in microseconds
DT: 100.

# DD is the nominal spatial correlation distance in km
# (should be at least DT*c = DT(sec) * 3*10^8(m/sec) =
DT(uS)*0.3(km/uS)
DD: 30.0

# MATCH is a true/false requirement for type-matching
MATCH: false

# START is the start data/time
# If not defined, starts at the beginnig of the later-start file
START: 2011-07-01@00:00:00

# STOP is the stop date/time
# If not defined, stops at the end of the earlier-stop file
STOP: 2011-07-30@23:59:59

# LATLON is the lat-lon rectangular boundry for analysis region
# in decimal degrees ( LL_lat LL_lon UR_lat UR_lon )
# If not defined, the whole region is used
LATLON: 36.,137.,41.,142.
```

Tool "Outputs"

- Analysis "Sheets"
  - Sheet 1: (overall timing, LA, and DE statistics)
    - Requires date, time, lat, lon, and (optionally) type (CG/CLD pulse)
  - Sheet 2: (peak current (Ip) calibration and DE vs. Ip)
    - Requires peak current estimates
  - Sheet 3: (data quality parameters)
    - Requires quality-related parameters
      - location error estimate
      - # sensors reporting the stroke/pulse
- Spatial Detection Efficiency
- Flash Analysis

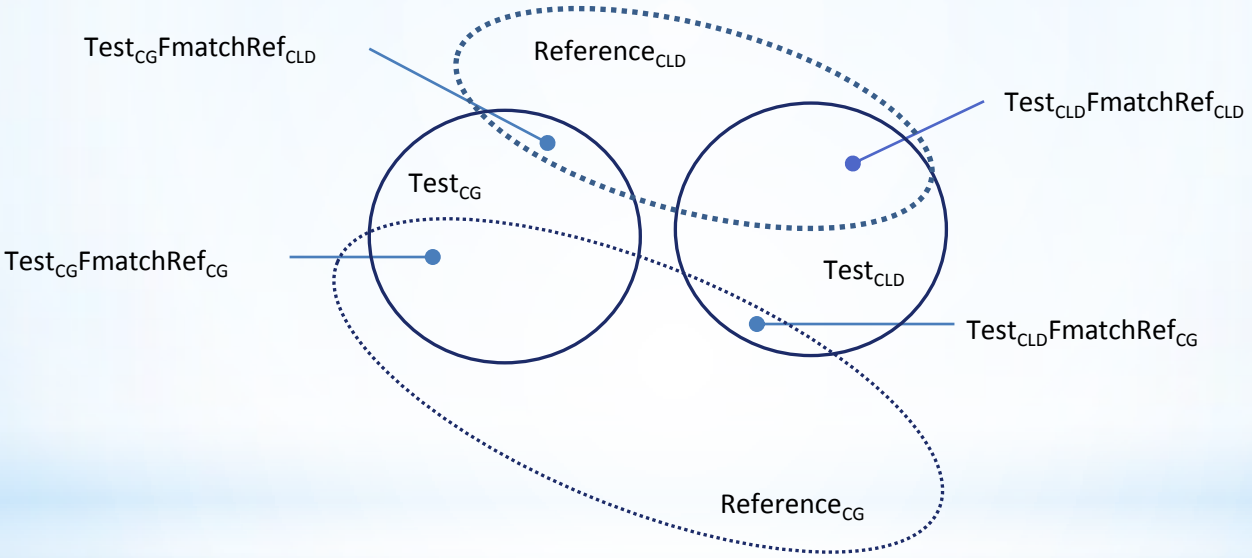
Spatial Detection Efficiency

* Observe spatial variation in DE
  * Combined for cloud pulses and CG strokes
* Helpful for selecting LLS comparison regions
* Automatic global country/coastline
* Example: CHUVA TLS200cg (ref) and GLD360 (test)



Flash Analysis Overview

- Definition of flash DE
  - This is complicated by the fact that LLS's frequently disagree about the discharge type (cloud vs. CG)



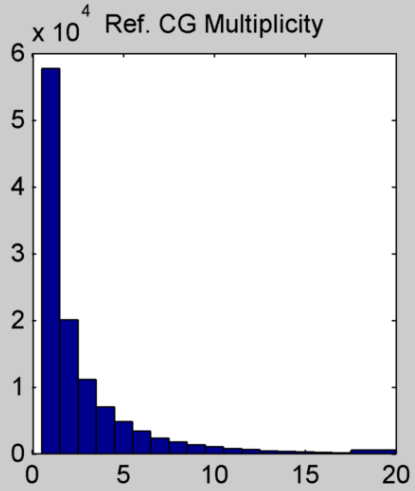
Examples:

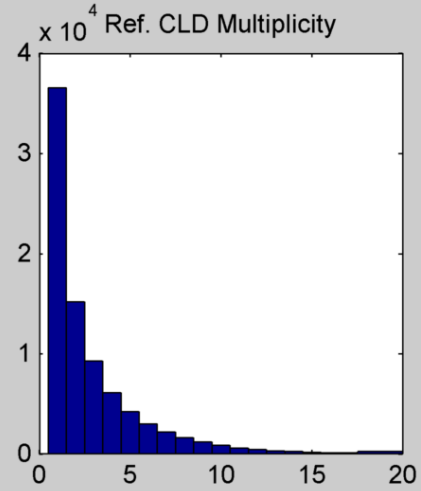
$$DE\_TestCGF = 100.*(Test_{CG}FmatchRef_{CG} + Test_{CLD}FmatchRef_{CG}) / (Ref_{CG}F);$$

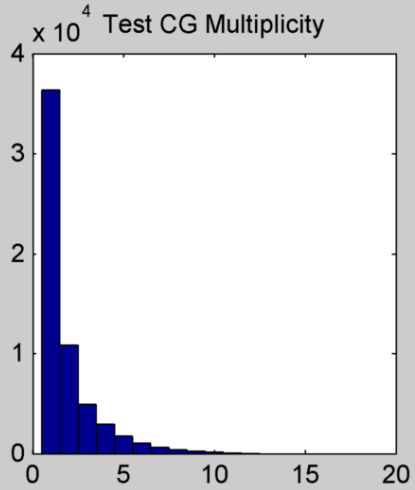
$$DE\_TestAll = 100.*allMatchTest/(Ref_{CG}F+Ref_{CLD}F);$$

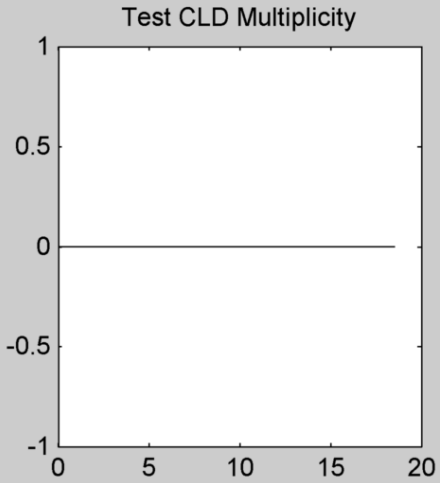
Details

Flash - CHUVA LINET vs. GLD360









LINET_GLD360.cfg -- accum -- 20-May-2014 23:48:25 -- 20120327_LINET_level1b.txt - accum - 2012.03.27.gld360.txt

Flash Analysis

max. ISI: 3.000000e-01 max. Rng: 30.0

------- Reference Network -----

---Type---	Flashes	Mult	PctFl
CG	114774	2.73	58.2
CLD	082542	2.87	41.8

*** IC:CG Flash Ratio 0.72

---Type---	Events	Mult	PctCLD
CLD-in-CG	210471	1.83	37.2
PreCG	118640	1.03	21.0

Flash Detection Efficiency

refCG	testCG	refCLD	testCLD	refAll	testAll
82.9	31.2	NaN	14.9	82.9	24.4

------- Test Network -----

---Type---	Flashes	Mult	PctFl
CG	060043	1.95	100.0
CLD	000000	NaN	0.0

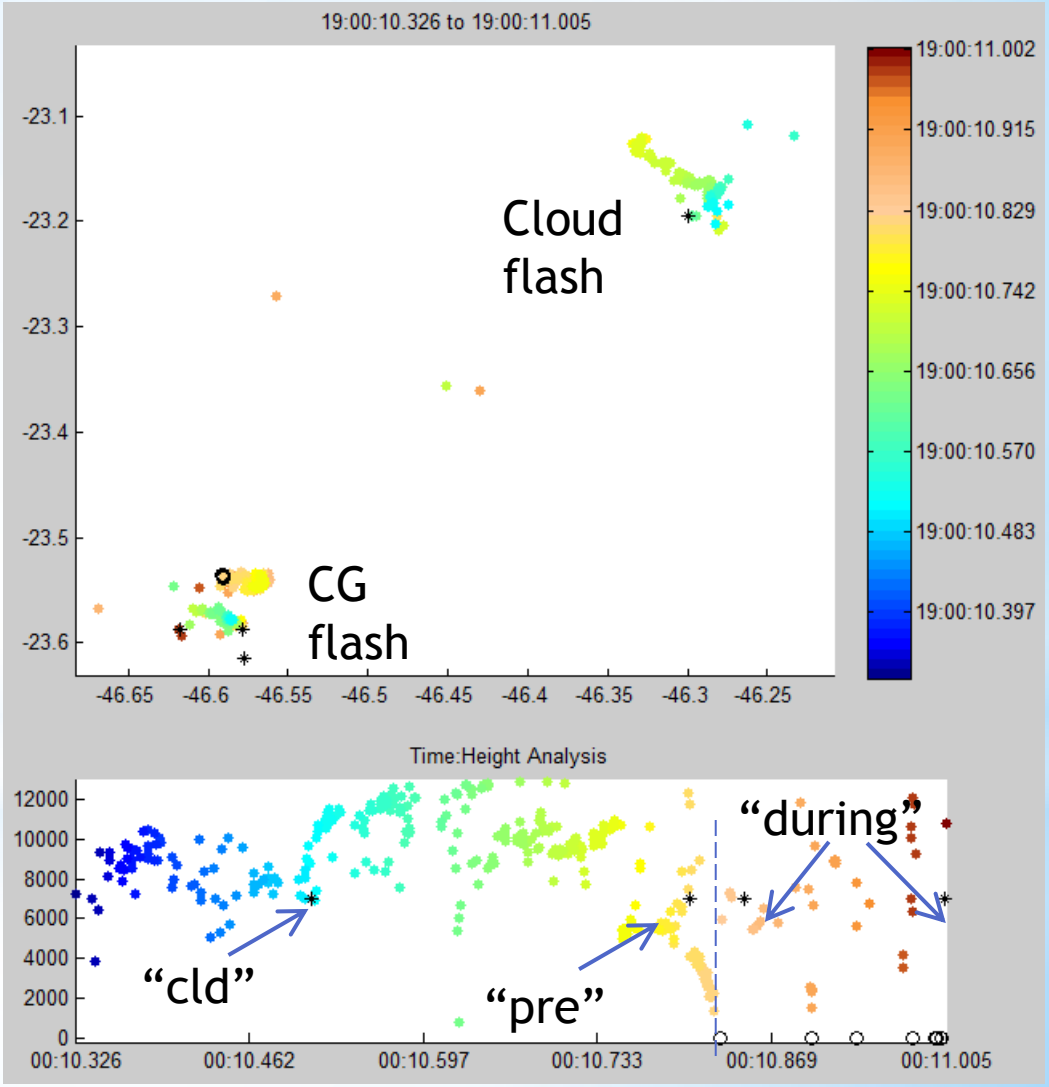
*** IC:CG Flash Ratio 0.00

---Type---	Events	Mult	PctCLD
CLD-in-CG	000000	0.00	NaN
PreCG	000000	0.00	NaN

Back?

Additional Flash Analysis: where *(in time)* are the LLS cloud pulses detected?

* The Flash Analysis includes a temporal analysis for each network
  * Are they part of a cloud flash?
  * Are they part of a CG flash?
  * What part of a CG flash?



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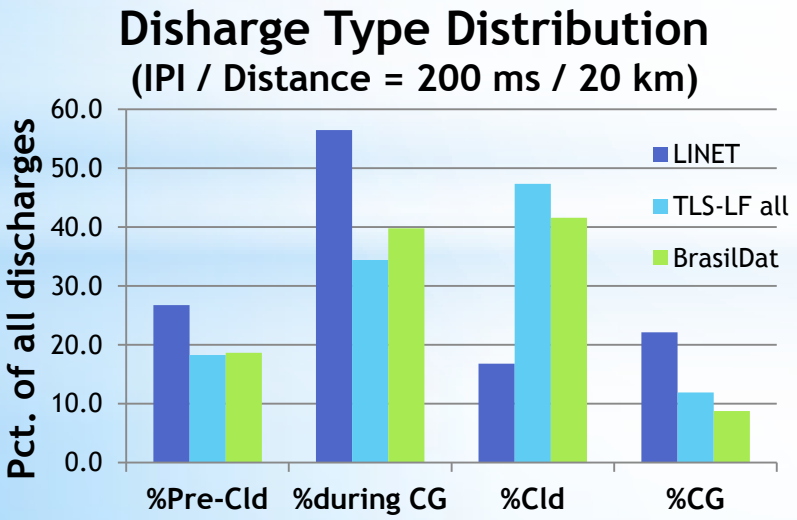
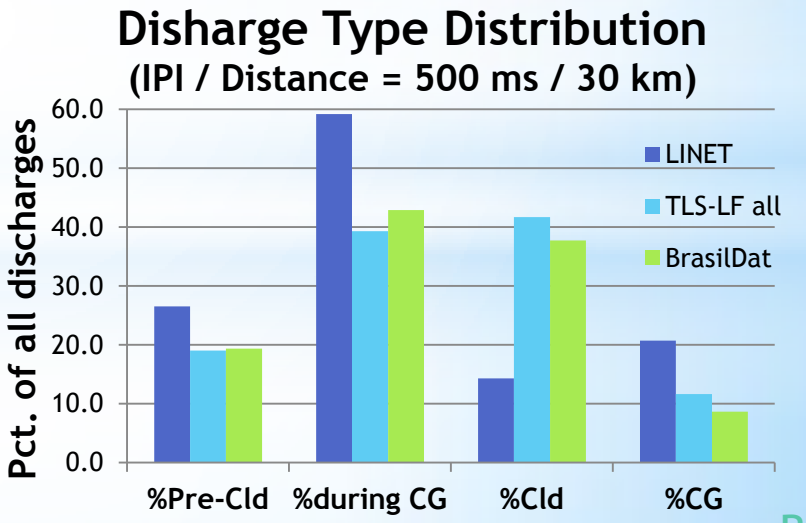
Temporal Analysis

- Limited to LLS's with both CLD and CG stroke detection
  - LINET, BrasilDat, and TLS-LF-all
- Large variation among the networks in terms of the types of reported discharges
  - LINET sees 83% of its cloud pulses associated with CG flashes
  - These findings are very dependent on the accuracy of type-classification





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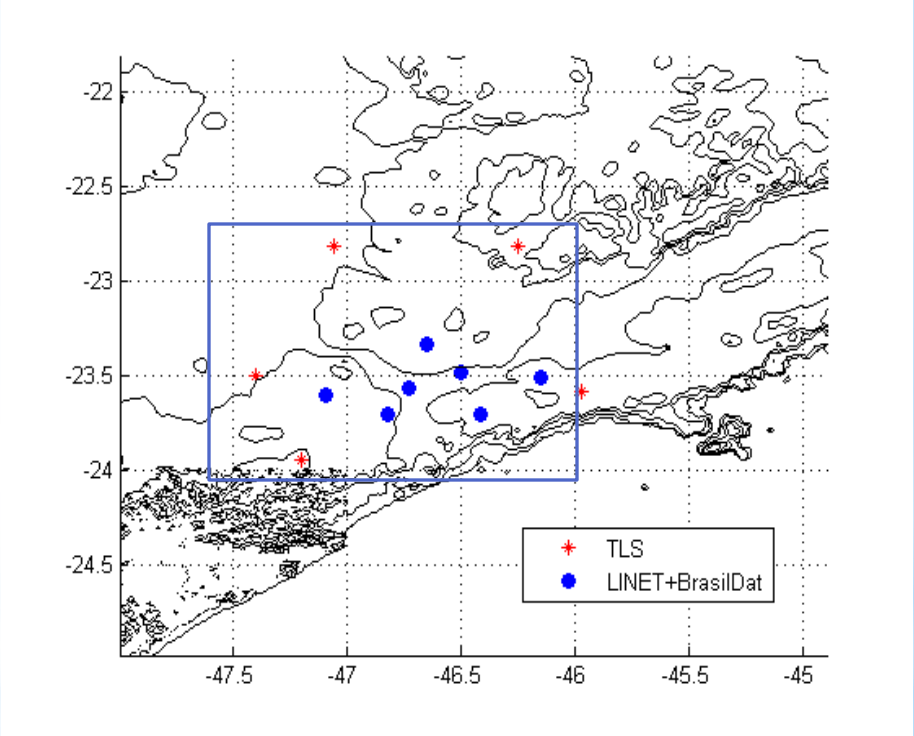
Example Use: LINET-referenced Comparison

- METHOD:
  - Selected a “common” (small) region and time period
    - Region determined by LINET
    - Time period limit defined by TLS200
      - 16 high-activity days between January 5 through March 27, 2012
        - Note: LINET is compromised during some of these times

Selection of the Analysis Domain: LINET Comparison

- The domain was selected to be optimal for LINET (Blue box)
- Does not necessarily provide a representative spatial sample for the long-range networks



Comments from data contributors

- WWLLN
  - The small domain and small number of flashes result in uncertainty in the WWLLN findings. Analysis over a larger domain should be done
- LINET
  - During much of this time, only 5 of the 7 sensors were operational.
  - Leap-second issue with LIS data?
- BrasilDat
  - Typically, only 1-2 of the 7 “special” sites were operational, and the network was just being calibrated. The network is now working much better than it was during the CHUVA campaign. (the ~100 km baseline in the previous slide reflected the “functional” baseline during this study)

* Comparison Table

Network	#TL Events	#Flash	Flash IC:CG	Rel FDE	mean DT	RMS DT	mean Dist.	median Dist	5% +IC Ip	50% +IC Ip	Ip slope	% pol. Match	Sensor baseline dist. (km)
LINET	882926	198405	0.72						1.5	3			22-45
TLS-LF "all"	538028	170418	2.03	65.4	18.3	16.56	3.21	1.46	1.5	3.5	1.22	89.4	55-125
BrasilDat	447098	189094	5.83	69.8	17.6	19.4	3.44	1.84	2	4.5	1.05	78.3	~100
TLS-LF CG	151094	55833	N/A	32.6	17.86	13	2.23	1.08	N/A	N/A	1.27	97.6	55-125
GLD360	117221	60043	N/A	24.2	20.2	18.61	7.1	4.61	N/A	N/A	1.07	88.7	big
StarNet*	51608	36676	N/A	19.1	-64.74	70.2	16.34	14.86	N/A	N/A	N/A	N/A	big
WWLLN*	15264	11463	N/A	6.2	14.14	26.53	7.12	5.68	N/A	N/A	N/A	N/A	big

*Note: Flash grouping parameters were relaxed to 500 ms and 50 km for these networks, due to low DE (both) and larger location errors (StarNet)

The flash grouping parameters for the other networks was 300 ms and 30 km

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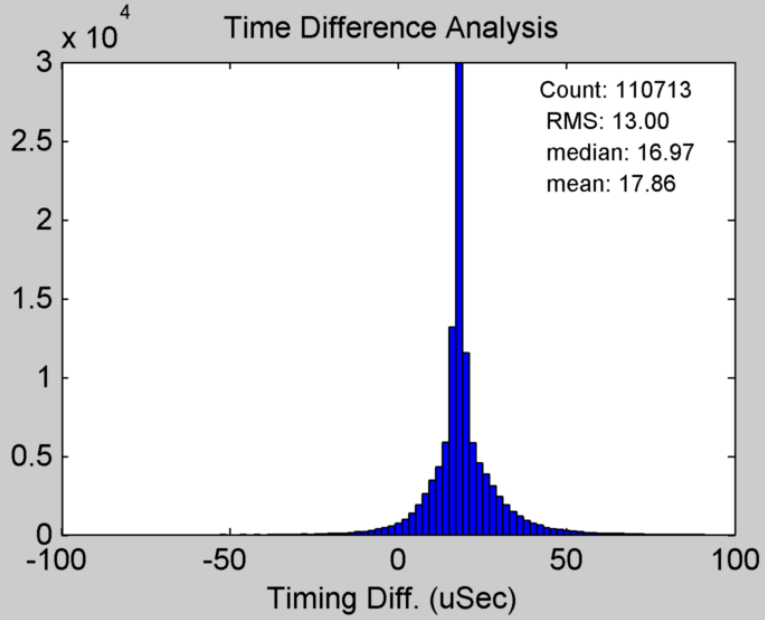
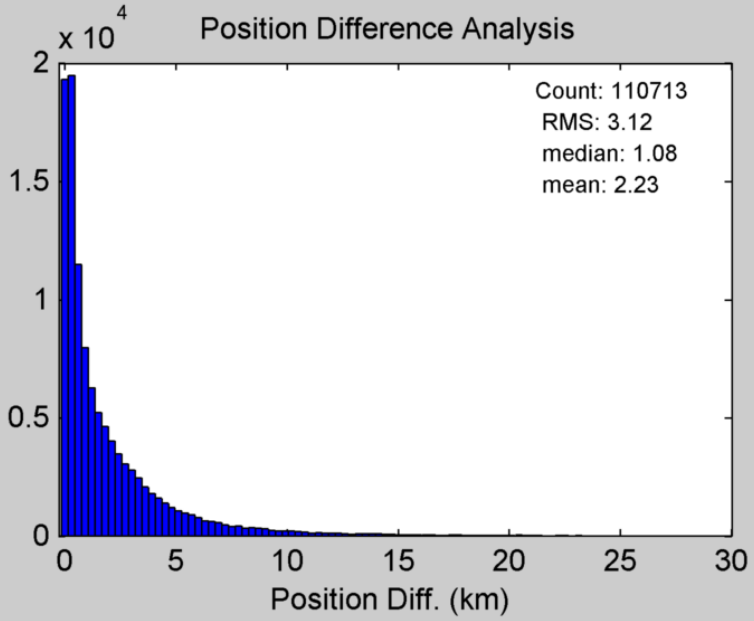
* Comparison Table: DE & IC:CG

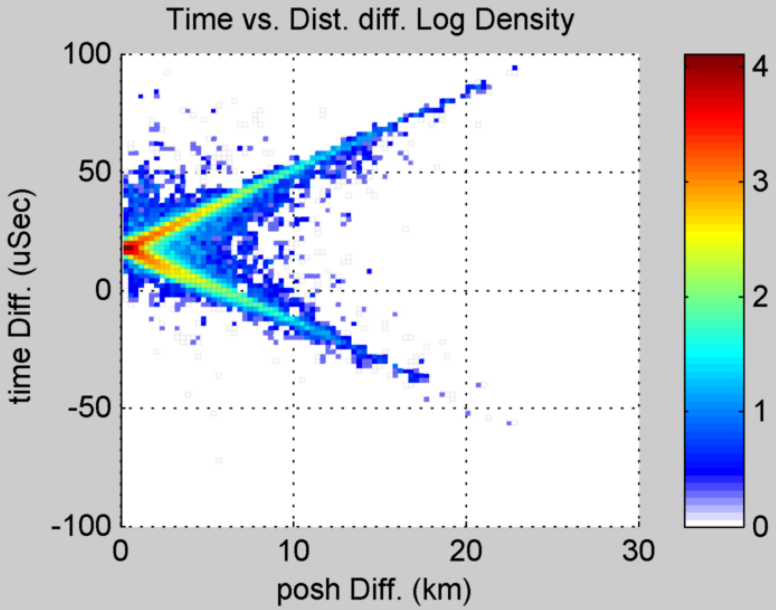
Netwrk	#TL Events	#Flash	Flash IC:CG	Rel FDE	Sensor baseline dist. (km)
LINET	882926	198405	0.72		22-45
TLS-LF "all"	538028	170418	2.03	65.4	55-125
BrasilDat	447098	189094	5.83	69.8	~100
TLS-LF CG	151094	55833	N/A	32.6	55-125
GLD360	117221	60043	N/A	24.2	big
StarNet*	51608	36676	N/A	19.1	big
WWLLN*	15264	11463	N/A	6.2	big

Note: LINET only reported 75-80% of the flashes reported by TLS and BrasilDat => all networks "see" some things that others do not

* Factor-of-50 variation in reported events
* Factor-of-20 variation in FDE
* "top 3" Networks:
  * event counts are inversely related to sensor baseline
  * nearly-equal flash counts
  * extremely different IC:CG ratios (=> classification issues)







LINET_TLS-LFcg.cfg -- accum -- 18-May-2014 21:28:55
Reference File: 20120327_LINET_level1b.txt
Test File: 20120327.asc

Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	312851 / (50.5)	566095 / (NaN)	110713 / (73.3)
Test:	151094 / (24.4)	0 / (0.0)	110713 / (12.6)

Classification Table:

	Test CG	Test CLD
Ref. CG	076312	000000
Ref. CLD	034401	000000

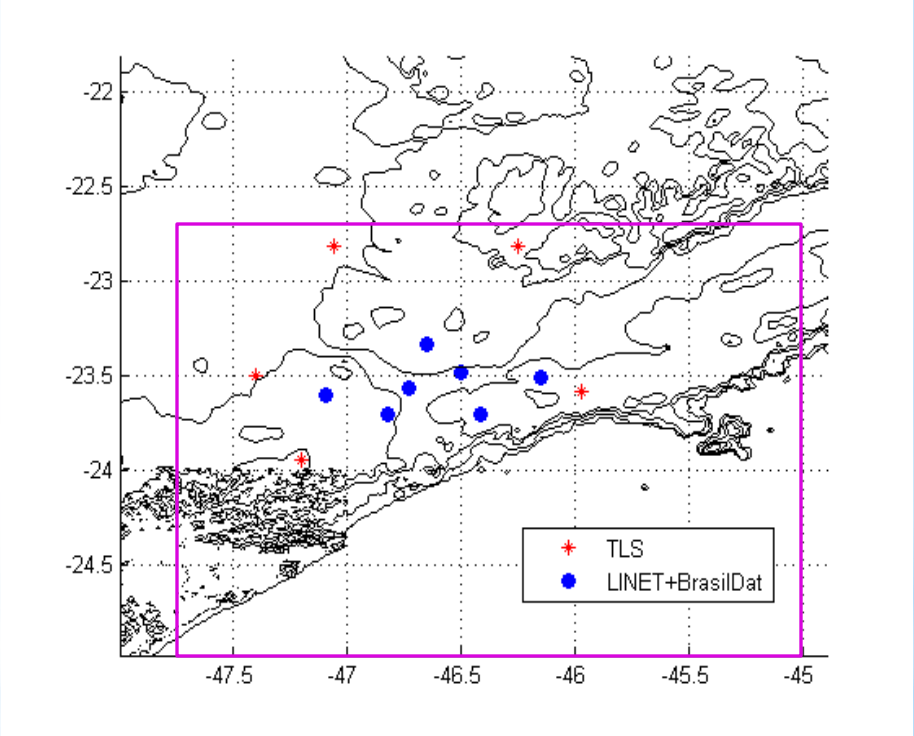
161 rej. for separation distance 0 rej. for Type mis-match

* Example Use: LIS-referenced DE

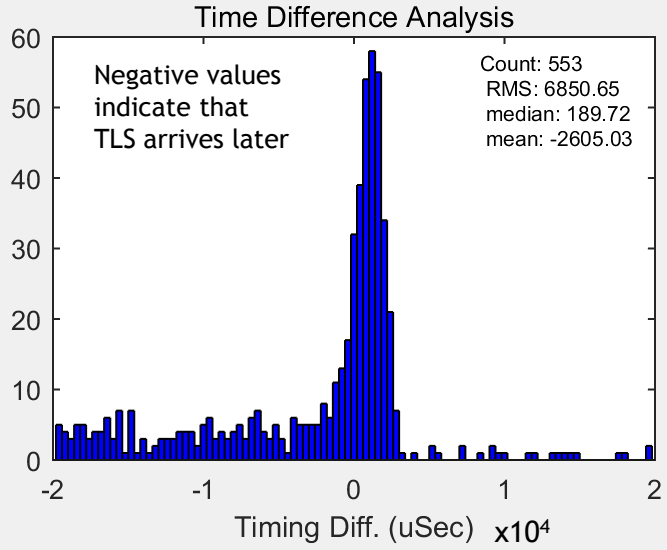
* Simple question: When LIS saw something, did others see it?
* METHOD:
  * Selected a "common" (small) region and time period
    * Region determined by LINET
    * Time period limit defined by TLS200
      * January 1 through March 27, 2012
        * Note: LINET is compromised during these times
    * Total Groups/Flashes were ~2900/300 in 13 overpasses
  * Use tools to compute group-referenced and Flash-referenced DE
    * Produce flashes from LIS Groups and LLS "events"
      * Multiple IPI/Distance Criteria for flash grouping: (200 ms/20 km; 500 ms/30 km; 500 ms /50 km for some long-range networks)

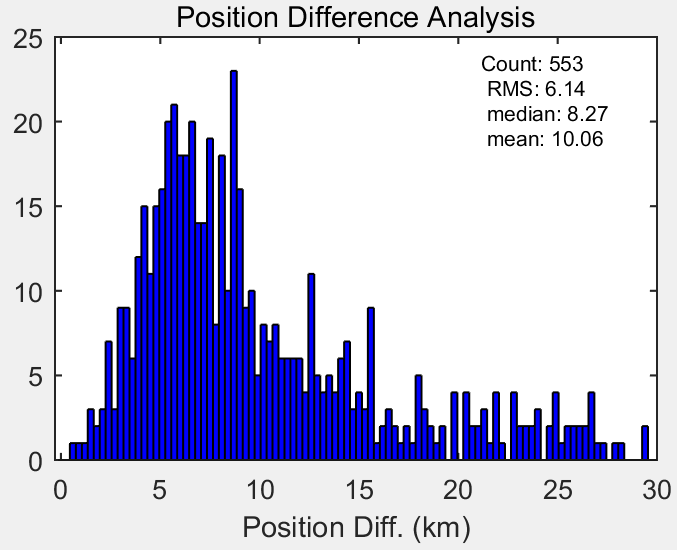
Selection of the Analysis Domain

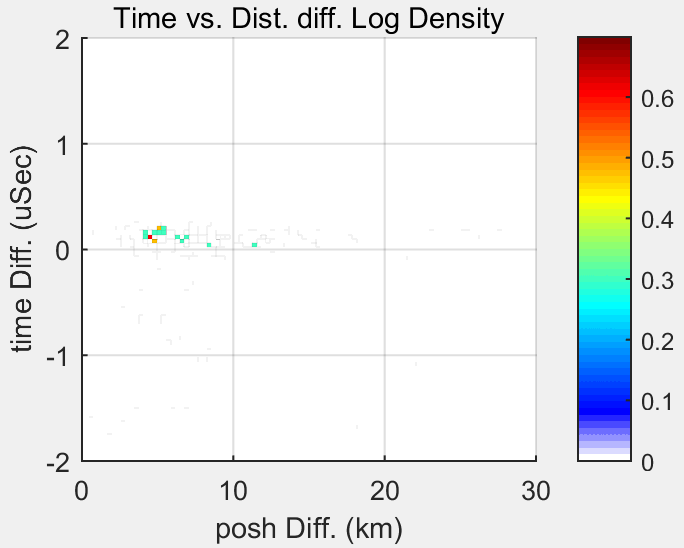
* Smaller domain would not have enough LIS flashes (< 300)
* The domain is quite large for LINET
  * confirmed that the LINET pulse/stroke DE, relative to TLS-LF-all, was not compromised over this domain



* Sheet 1 - LIS Groups vs. TLS200 LF







LIS_TLSlf_all.cfg -- accum -- 20-May-2015 23:26:44
Reference File: LIS-LMA-2012-03-27_19_01_11_03152_LIS.txt
Test File: 2012.03.27_TLSall.asc

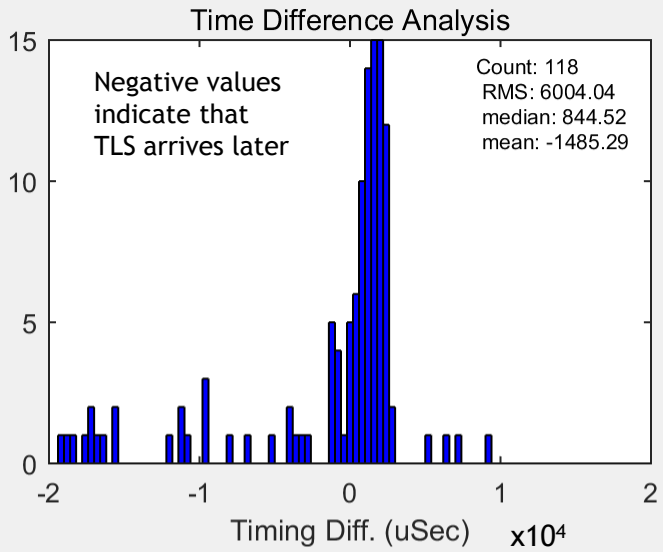
Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	2888 / (0.2)	0 / (0.0)	553 / (0.4)
Test:	44230 / (3.8)	87718 / (NaN)	553 / (19.1)

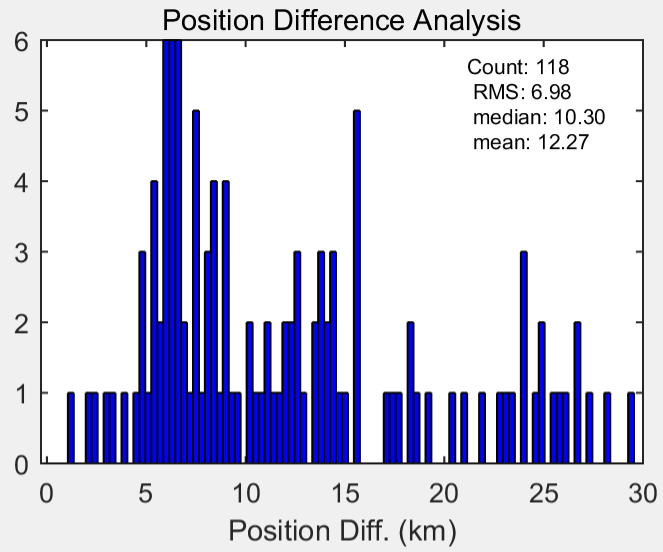
Classification Table:

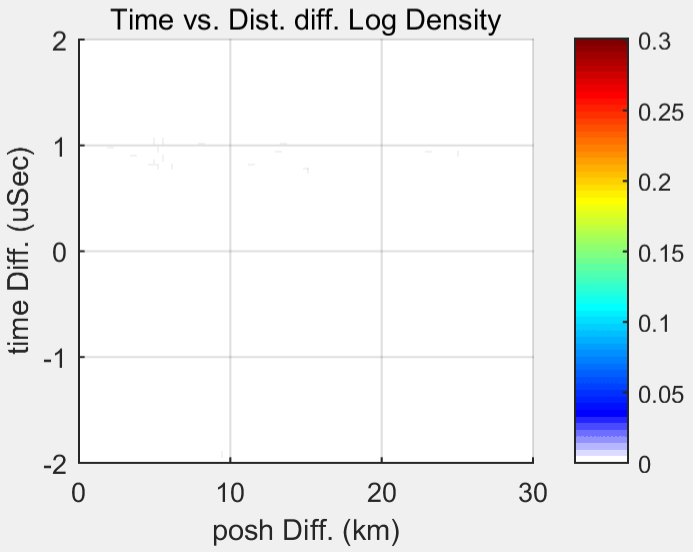
	Test CG	Test CLD
Ref. CG	000109	000444
Ref. CLD	000000	000000

921 rej. for separation distance 0 rej. for Type mis-match

* Sheet 1 - LIS Groups vs. TLS200 LF







LIS_TLSlf_CG.cfg -- accum -- 20-May-2015 23:27:42
Reference File: LIS-LMA-2012-03-27_19_01_11_03152_LIS.txt
Test File: 20120327.asc

Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	2889 / (0.3)	0 / (NaN)	118 / (0.3)
Test:	44249 / (4.1)	0 / (NaN)	118 / (4.1)

Classification Table:

	Test CG	Test CLD
Ref. CG	000118	000000
Ref. CLD	000000	000000

363 rej. for separation distance 0 rej. for Type mis-match

Flash Summary Statistics

Flash Grouping (IPI/Dist)	LLS Network	Relative Group DE	Relative Flash DE	Mean Groups/fl	Mean Mult. (G/C)	Nominal Sensor Baseline in test region
200/20	LINET	32.0	**61**	8.4	3.3/3.2	22-45 km
200/20	TLS-LF "all"	23	**56**	8.4	2.4/1.9	55-125 km
200/20	BrasilDat	15	**45**	8.4	1.8/3.3	~100 km
200/20	GLD360	5	**17**	8.4	2.4/0.0	>big
200/20	TLS-LF CG	6	**13**	8.4	3.3/0.0	55-125 km
200/20	StarNet	2	**8**	8.4	1.6/0.0	>big
200/20	WWLLN	1	**2**	8.4	1.7/0.0	>big
(estimated uncertainty of about +/-2%)						
500/30	LINET	32	67	9.2	3.5/3.4	22-45 km
500/30	TLS-LF "all"	23	67	9.2	3.0/2.8	55-125 km
500/30	BrasilDat	15	53	9.2	1.8/3.6	~100 km
500/30	GLD360	5	24	9.2	2.8/0.0	>big
500/30	TLS-LF CG	6	19	9.2	3.5/0.0	55-125 km
500/50	StarNet	2	14	10.3	2.0/0.0	>big
500/50	WWLLN	1	5	10.4	2.0/0.0	>big

Summary / Comments

* LLS Relative Performance vs. LIS Total Lightning
  * Wide variation in TL flash DE (few percent => ~70%)
  * Short-baseline VLF/LF networks CAN detect a majority of TL flashes (but do not represent the spatial extent of big flashes)
    * Note: Hartmut indicates that for days with all LINET sensors working, they would detect almost all LIS flashes that were within the network, as well as some flashes not reported by LIS
  * Some long-range LF networks MIGHT be sufficiently good to allow statistical up-scaling of the data for mid-oceanic LIS proxy and validation activities

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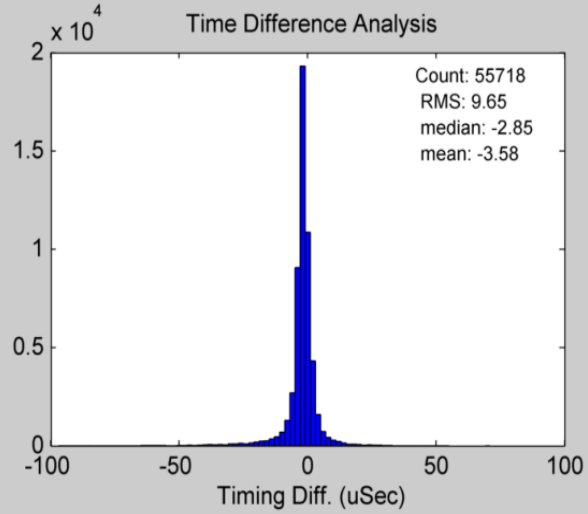
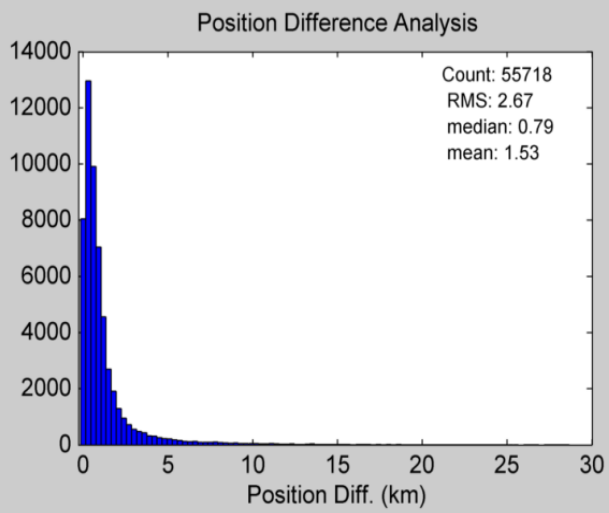
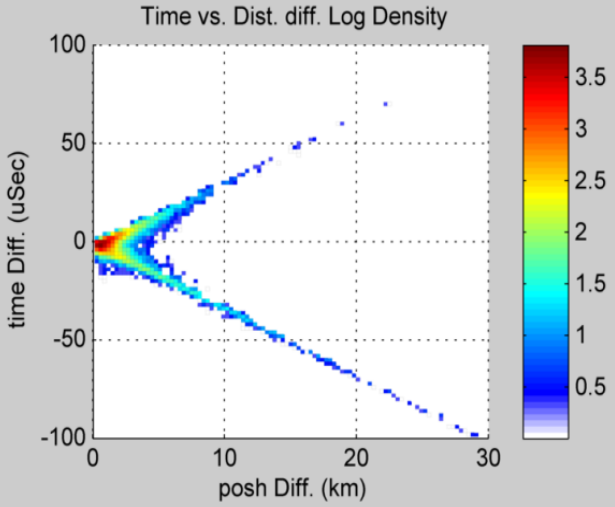
End of talk…

- Thanks!

* Sheet 1 - two networks in Japan







SampleSpec.cfg 03-Nov-2013 15:09:11
Reference File: data/sampleRef.asc
Test File: data/sampleTest.asc

Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	62594 / (72.7)	2102 / (0.6)	55718 / (70.8)
Test:	74902 / (87.0)	3841 / (1.1)	55718 / (86.1)

Classification Table:

	Test CG	Test CLD
Ref. CG	054461	000006
Ref. CLD	001228	000023

57 rej. for separation distance 0 rej. for Type mis-match

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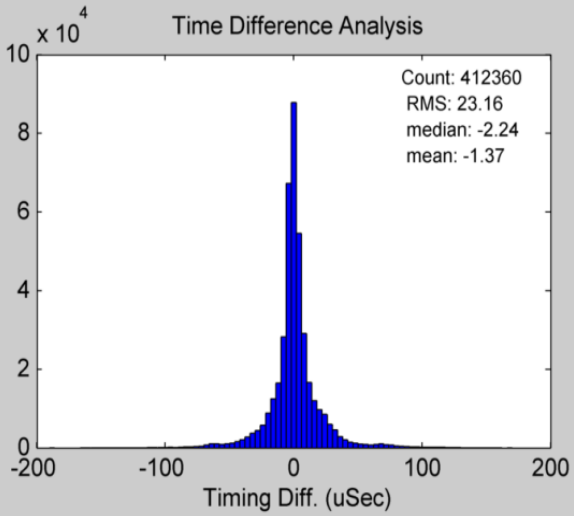
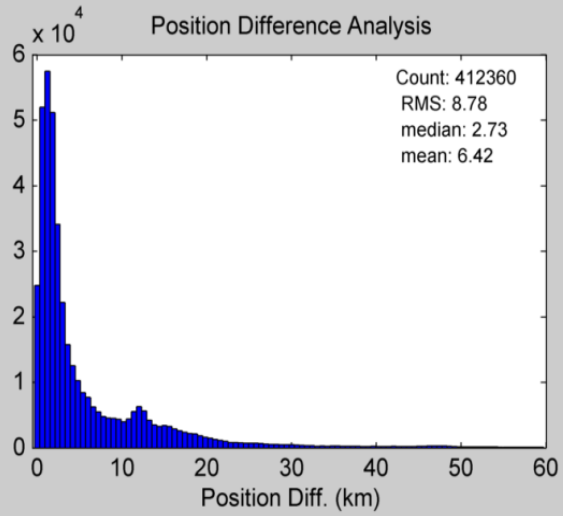
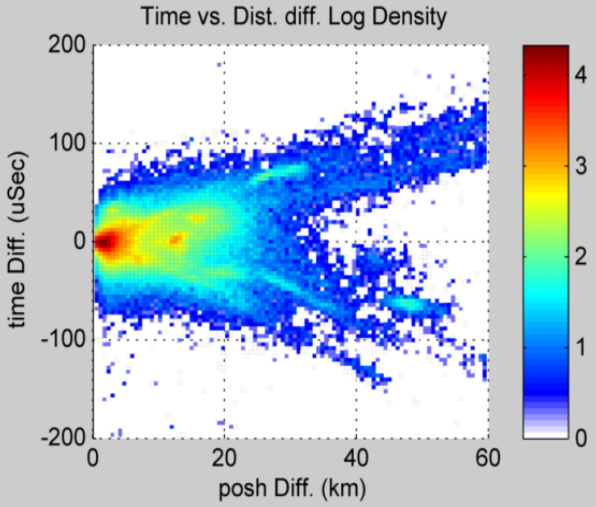
Sheet 1 - GLD360 vs. NALDN







NLDN_GLDrepNew.cfg 04-Nov-2013 07:03:18
Reference File: data/2011-08-04_NALDN.txt
Test File: data/2011_08_04_gldCluster

Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	820524 / (47.6)	639464 / (NaN)	412360 / (61.9)
Test:	665845 / (38.6)	0 / (0.0)	412360 / (28.2)

Classification Table:

	Test CG	Test CLD
Ref. CG	316817	000000
Ref. CLD	095543	000000

13334 rej. for separation distance 0 rej. for Type mis-match

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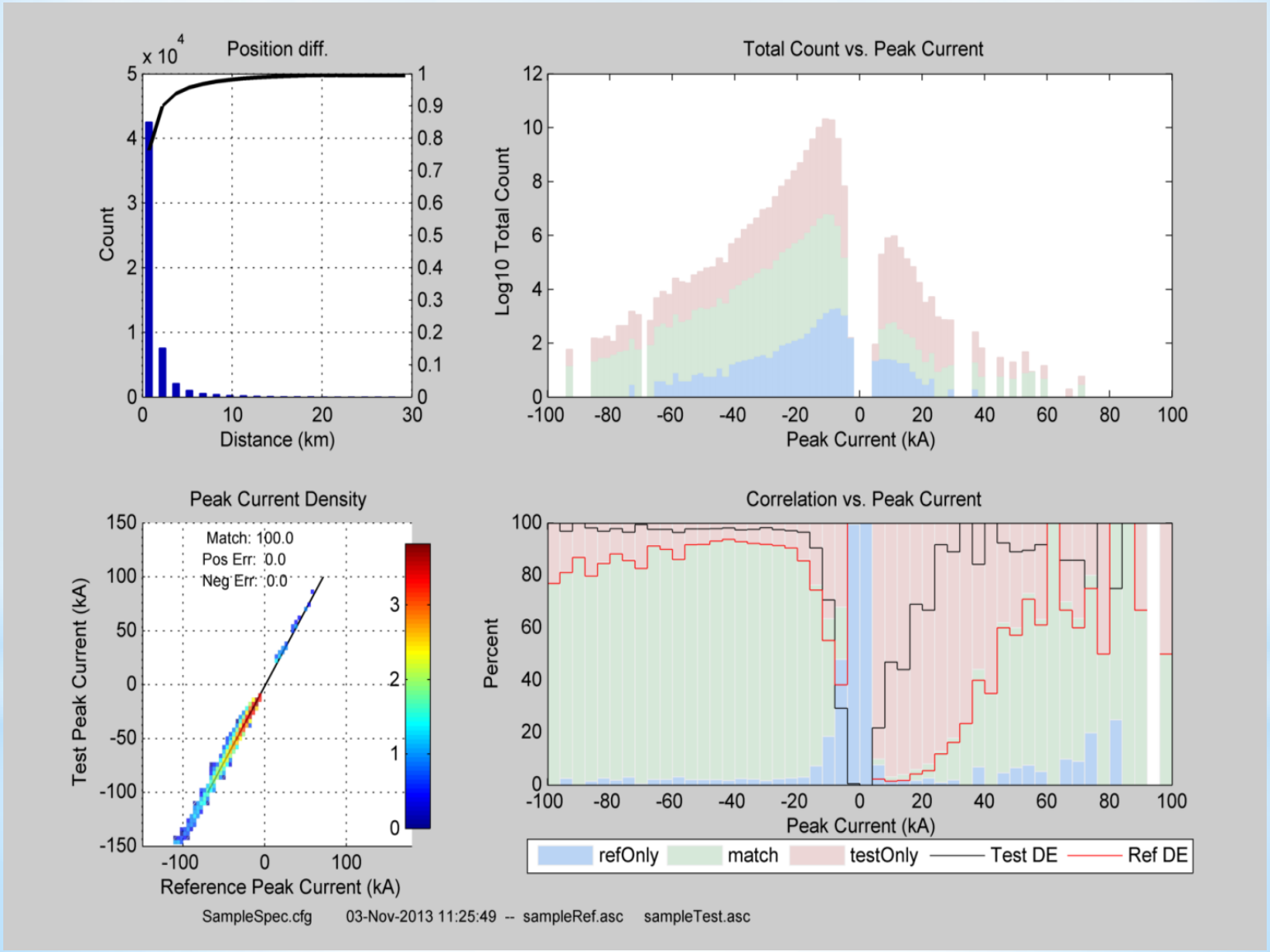
* Sheet 2 - two networks in Japan



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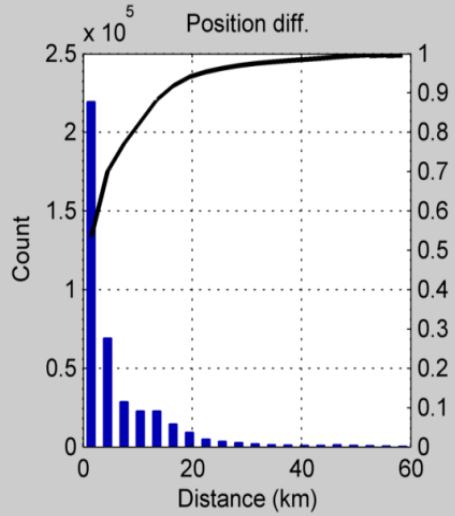
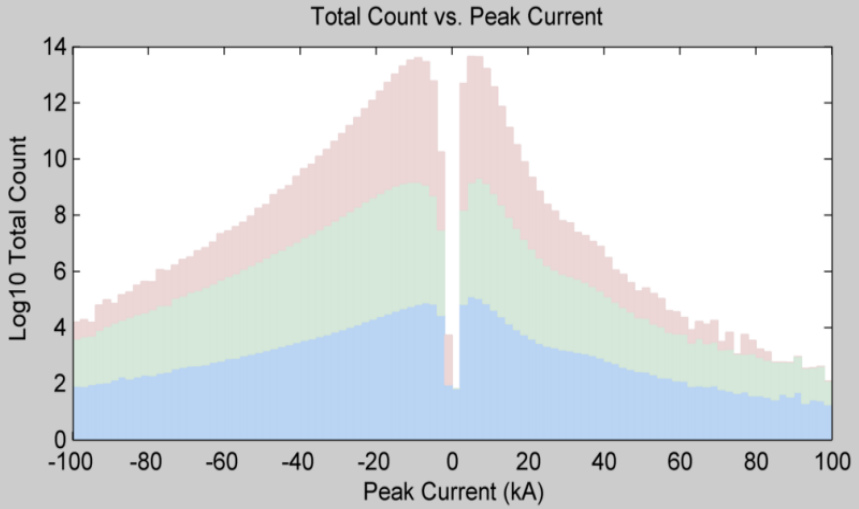
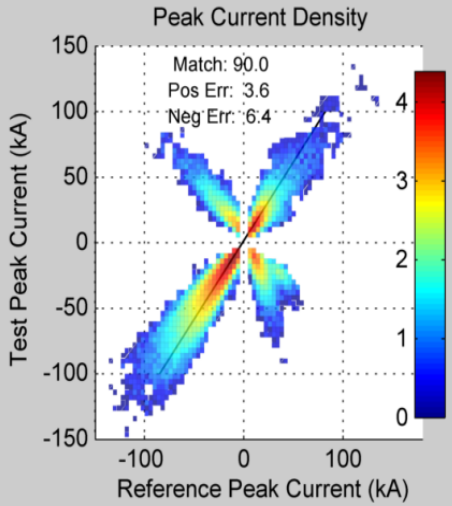
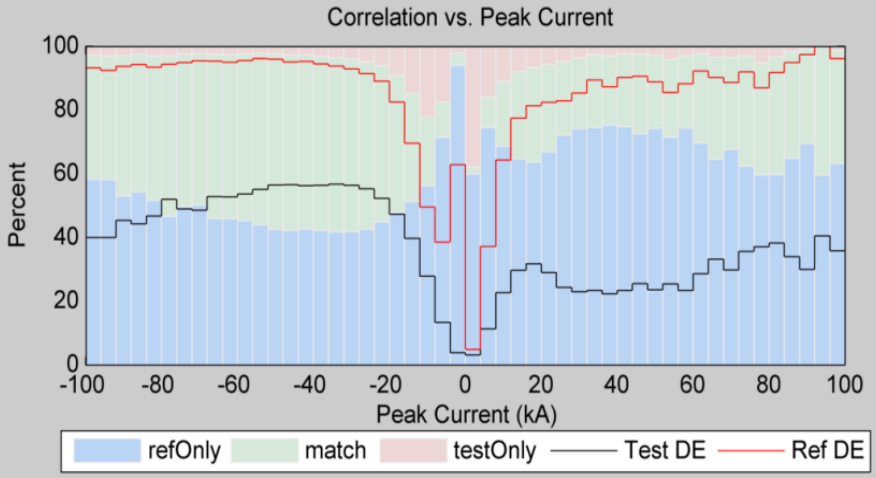
* Sheet 2 - GLD360 vs. NALDN









NLDN_GLDrepNew.cfg 04-Nov-2013 07:03:18 -- 2011-08-04_NALDN.txt 2011_08_04_gldCluster

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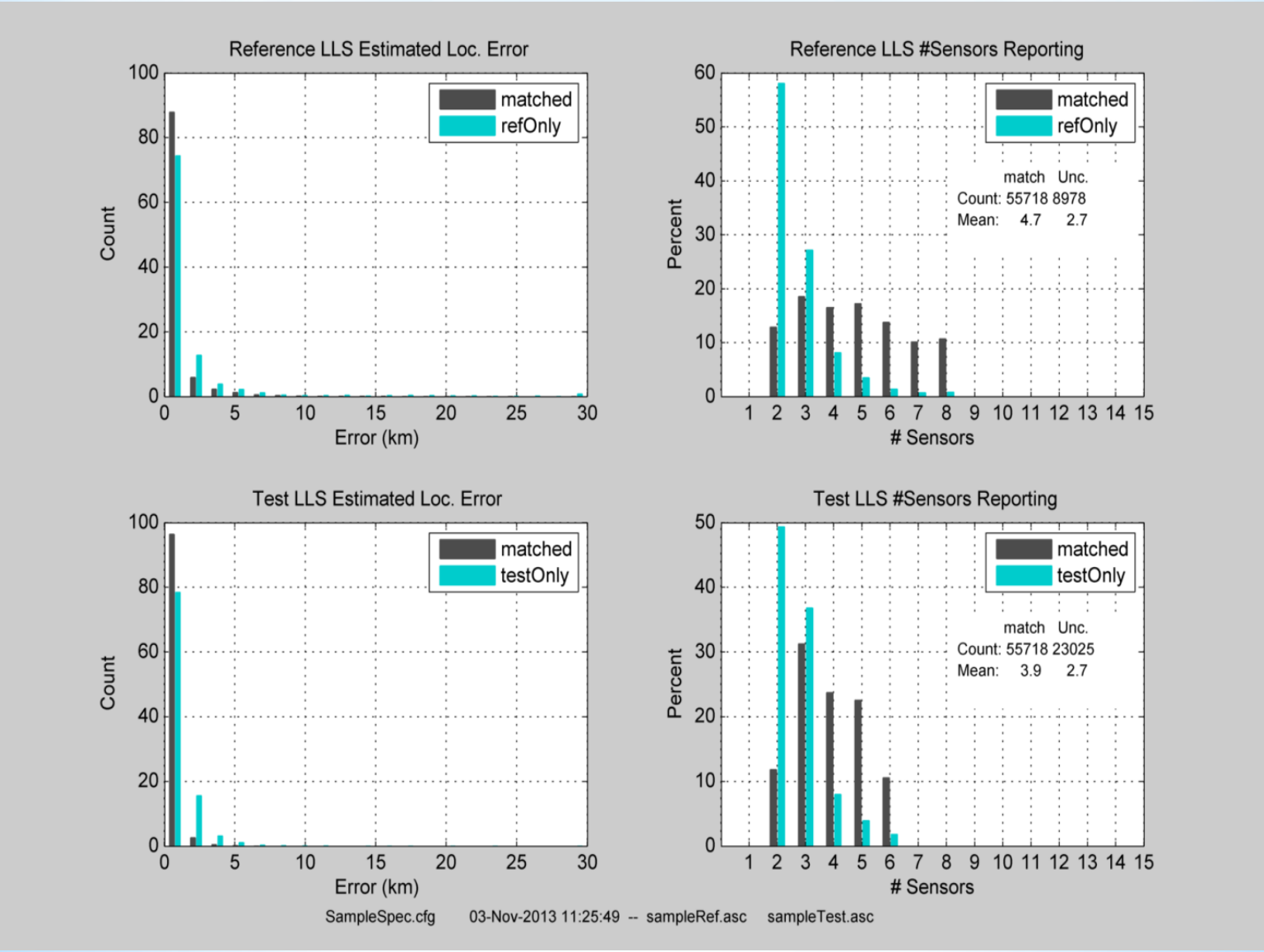
* Sheet 3 - two networks in Japan



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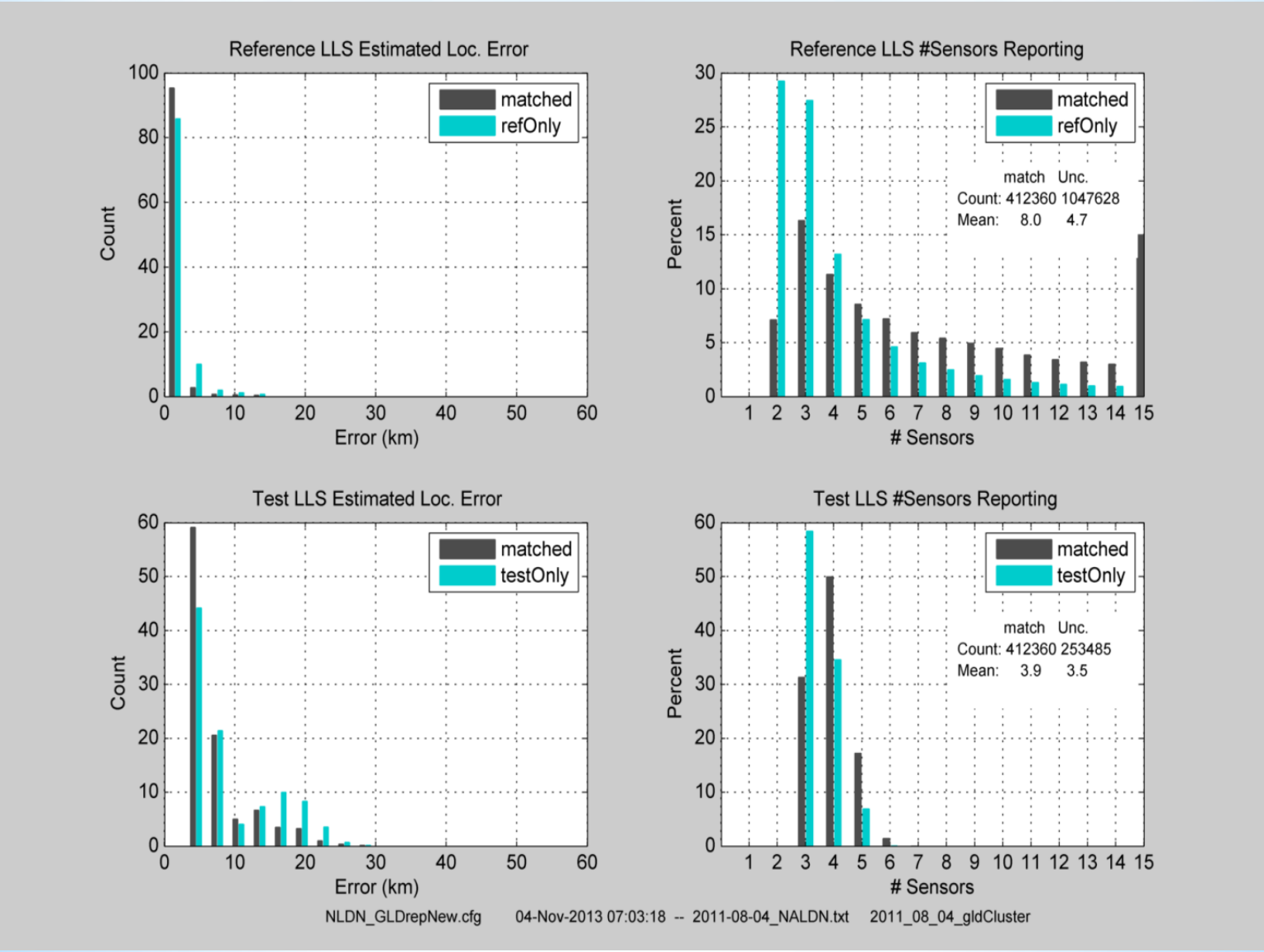
Sheet 3 - GLD360 vs. NALDN



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Flash Analysis Overview

* Flash Grouping (within an individual LLS dataset)
  * New flash is initiated if there are no "active" flashes within the max inter-pulse interval (IPI) and within the max separation distance *(typically 200 mS and10 km for "accurate" LLS's)*
  * If there is a match with more than one active flash, then the new pulse is added to the flash with the spatially-closest pulse
  * A flash is "closed" if the time between the most-recent pulse and the first pulse in the flash is greater then the max flash duration *(typically 1 second)*

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Flash Analysis Overview

- Flash / Pulse "Typing"
  - Pulses within a CG flash are categorized as one of three types:
    - "pre" cloud: likely preliminary breakdown or leader pulse
    - "during" cloud: k-changes etc.
    - "CG" stroke: we think we knew what this is…
  - Any flash containing a CG stroke is a CG flash

- A flash is detected in-common by two LLS's if:
  - Any pulse in the flash is matched using the tight requirements employed by the Inter-comparison Tool
  - Any "unmatched" pulses in the flash meet the max IPI/Distance requirements when compared to any pulse from the other LLS

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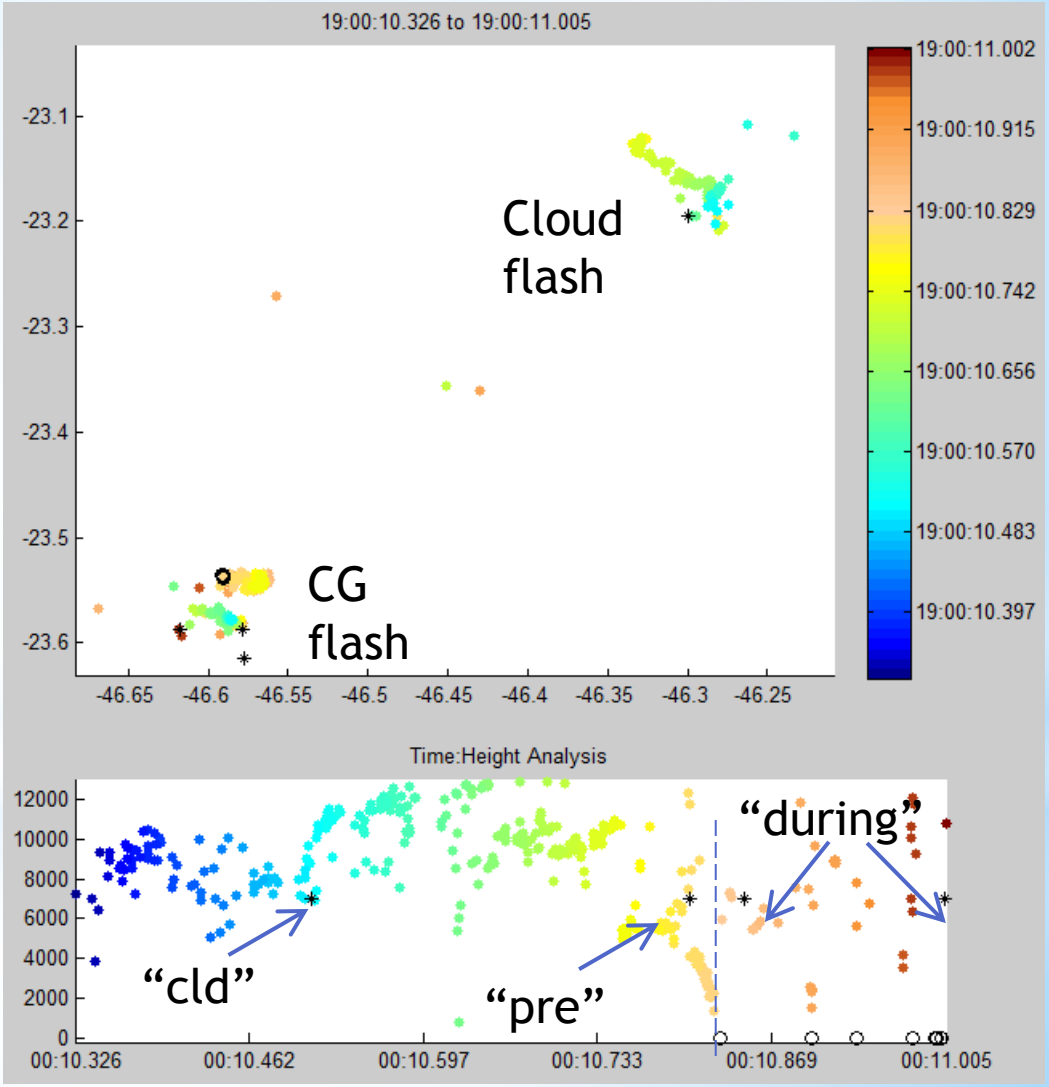
Additional Flash Analysis: where *(in time)* are the LLS cloud pulses detected?

* The Flash Analysis includes a temporal analysis for each network
  * Are they part of a cloud flash?
  * Are they part of a CG flash?
  * What part of a CG flash?



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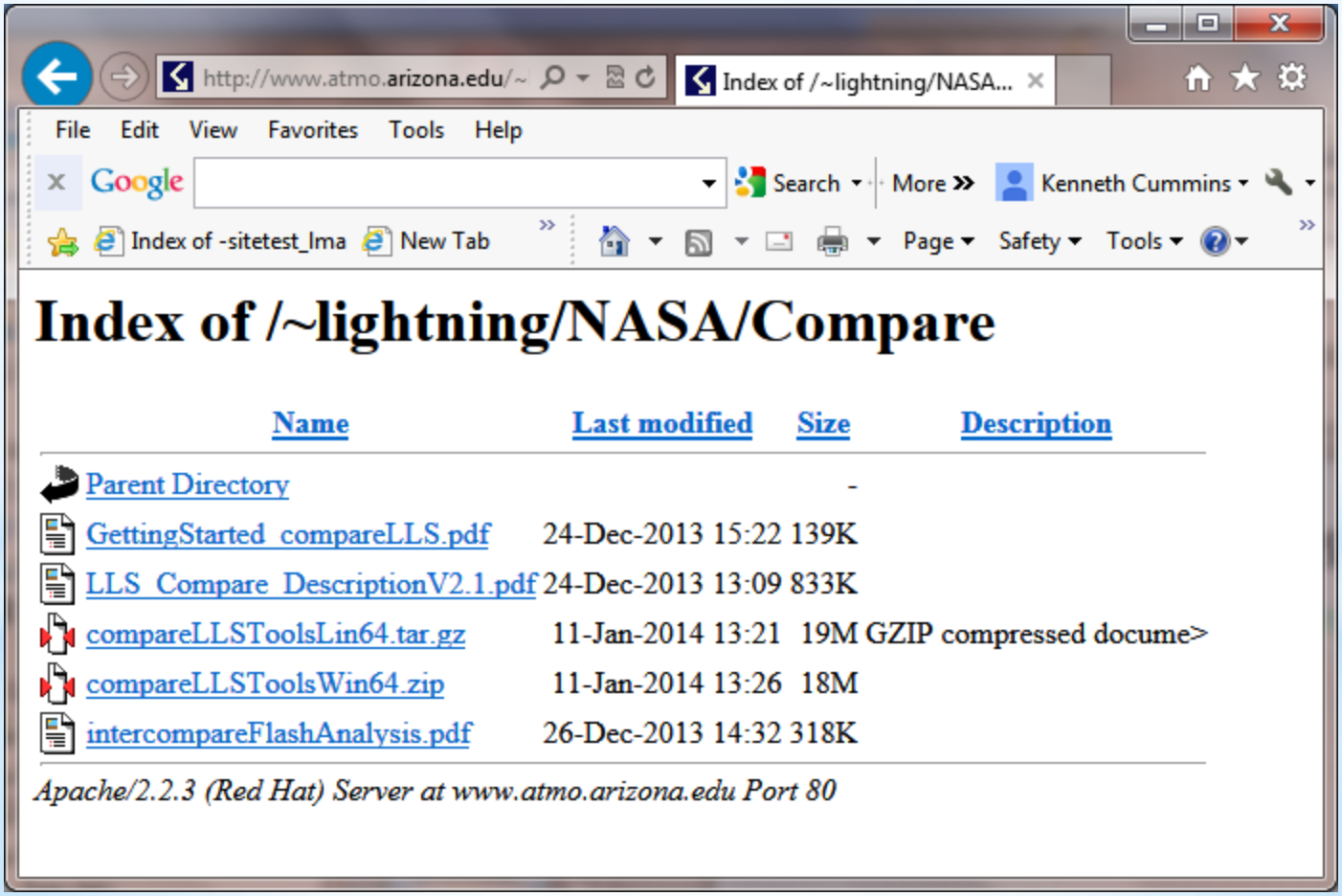
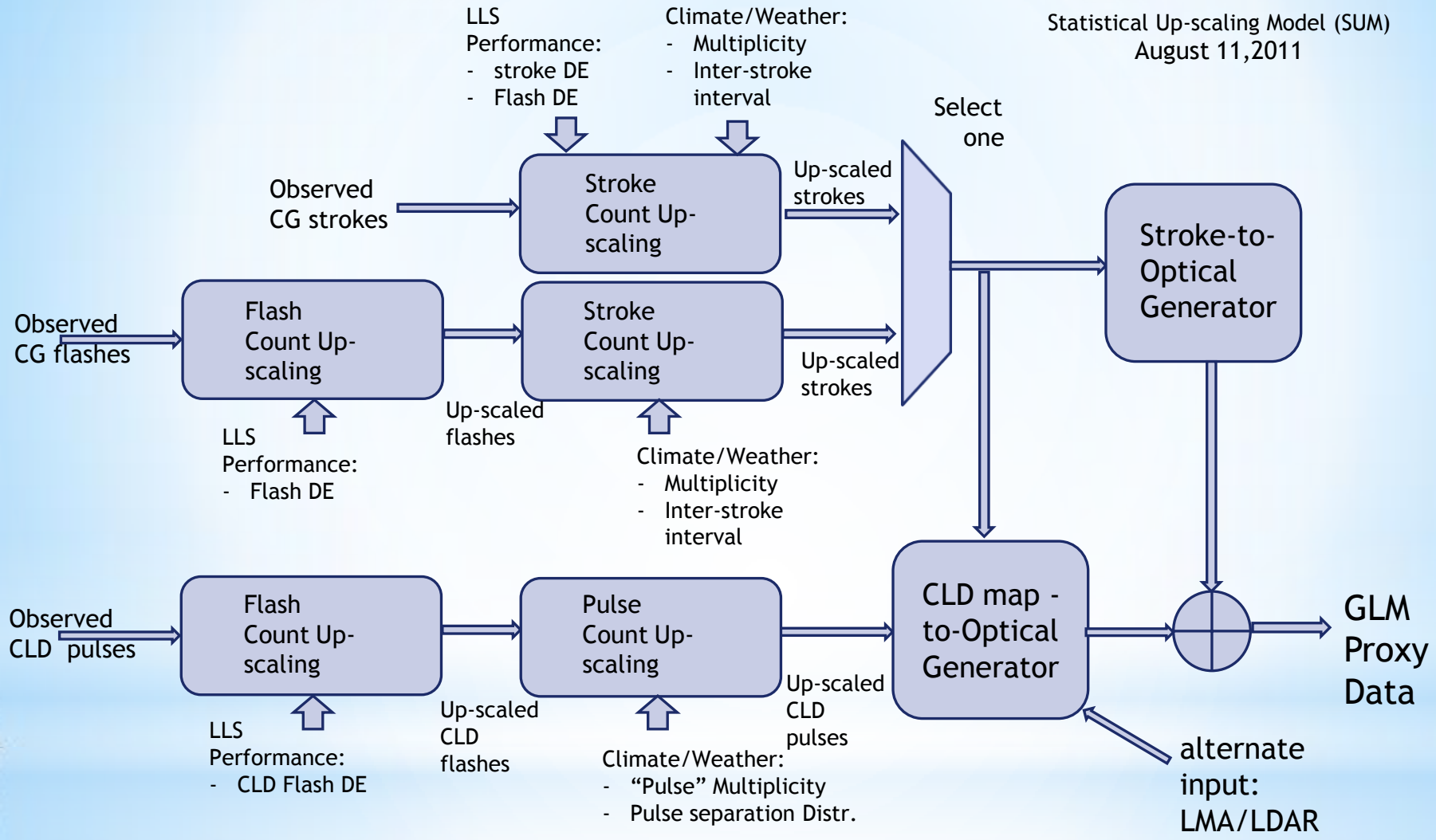
Extra Slides

How to get the stuff…

http://Atmo.Arizona.edu/~lightning/NASA/Compare/





Up-scaling Methods:

distribution Matching Spatial Interpolation Spatial Convolution