* On the Relationship between Observations from the Lightning Imaging Sensor and Ground-based Lightning Observations at VLF, LF, and VHF Frequencies - *A continuation…*

Kenneth L. Cummins[1], Richard J. Blakeslee[2] , Lawrence D. Carey[3], Jeff C. Bailey[3], Monte Bateman[4], Steven J. Goodman[5]

[1] *University of Arizona, Tucson, Arizona*
[2] *NASA Marshall Space Flight Center, Huntsville, Alabama*
[3] *University of Alabama in Huntsville, Huntsville, Alabama*
[4] *USRA, Huntsville, Alabama*
[5] *NOAA NESDIS, Greenbelt, Maryland*

GLM Science Meeting 2013

*LLS Inter-comparison Tool

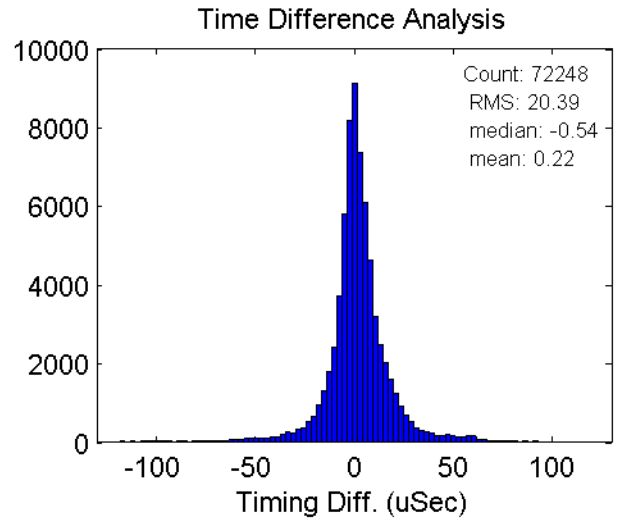
* Coded in Matlab
* Stand-alone executables can run on Unix, Linux, and Windows
* Can specify datasets and related parameters in a "cfg" file using a text editor…

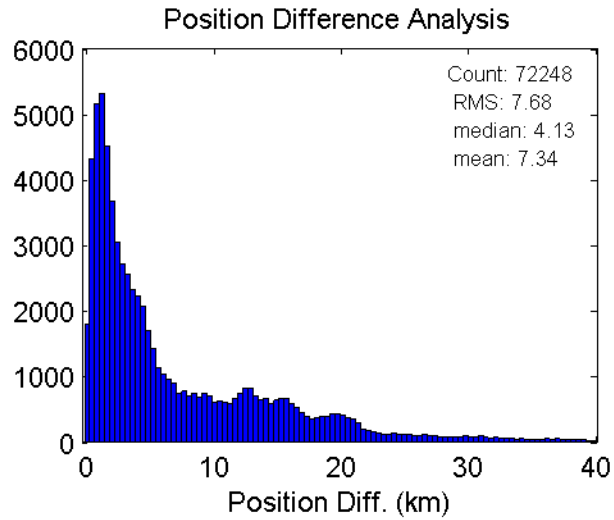
```
# sample Spec file for LLS comparison
# written by Ken Cummins,  July 2011

# 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.
```

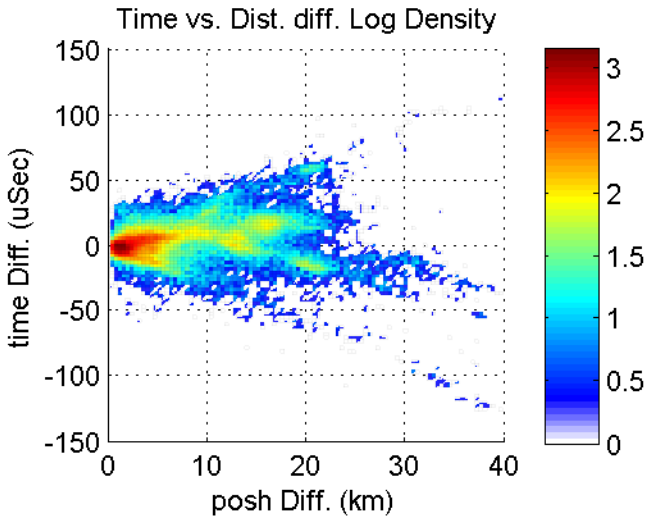
* Tool "Outputs"

* Analysis "Sheets"
  * Sheet 1:
    * Requires date, time, lat, lon, and (optionally) type (CG/CLD pulse)
  * Sheet 2:
    * Requires peak current estimates
  * Sheet 3:
    * Requires quality-related parameters
      * location error estimate
      * # sensors reporting the stroke/pulse
* Spatial Detection Efficiency
* Flash Analysis

* Sheet 1 - CHUVA TLS-all vs. GLD360







GLD_TLS-LFall.cfg -- accum -- 02-Sep-2013 11:39:28
Reference File: 2012.01.05_TLSall.asc
Test File: 2012.01.05.gld360.txt

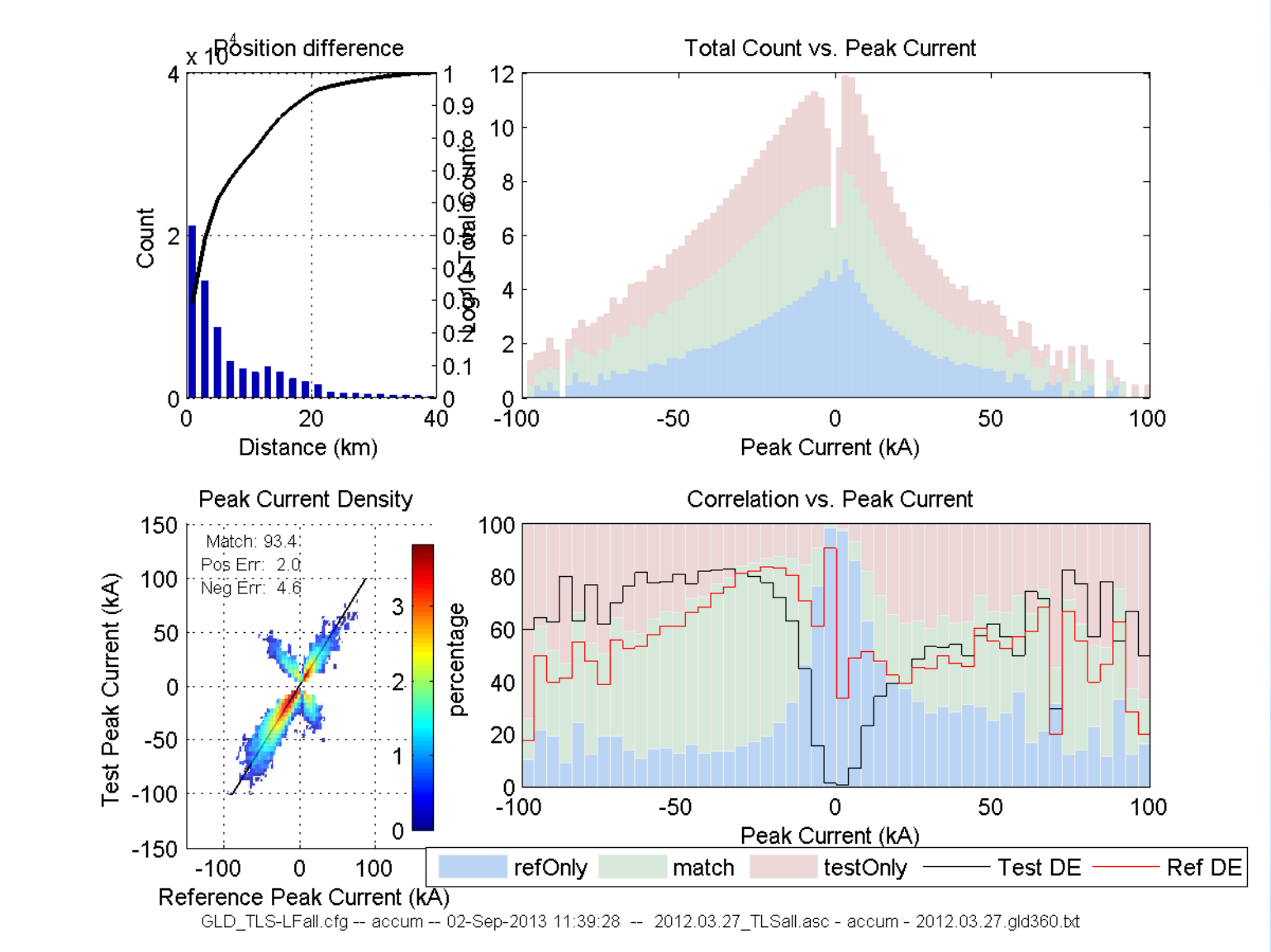
Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	131952 / (53.0)	345968 / (NaN)	72248 / (67.2)
Test:	107495 / (43.2)	0 / (0.0)	72248 / (15.1)

Classification Table:

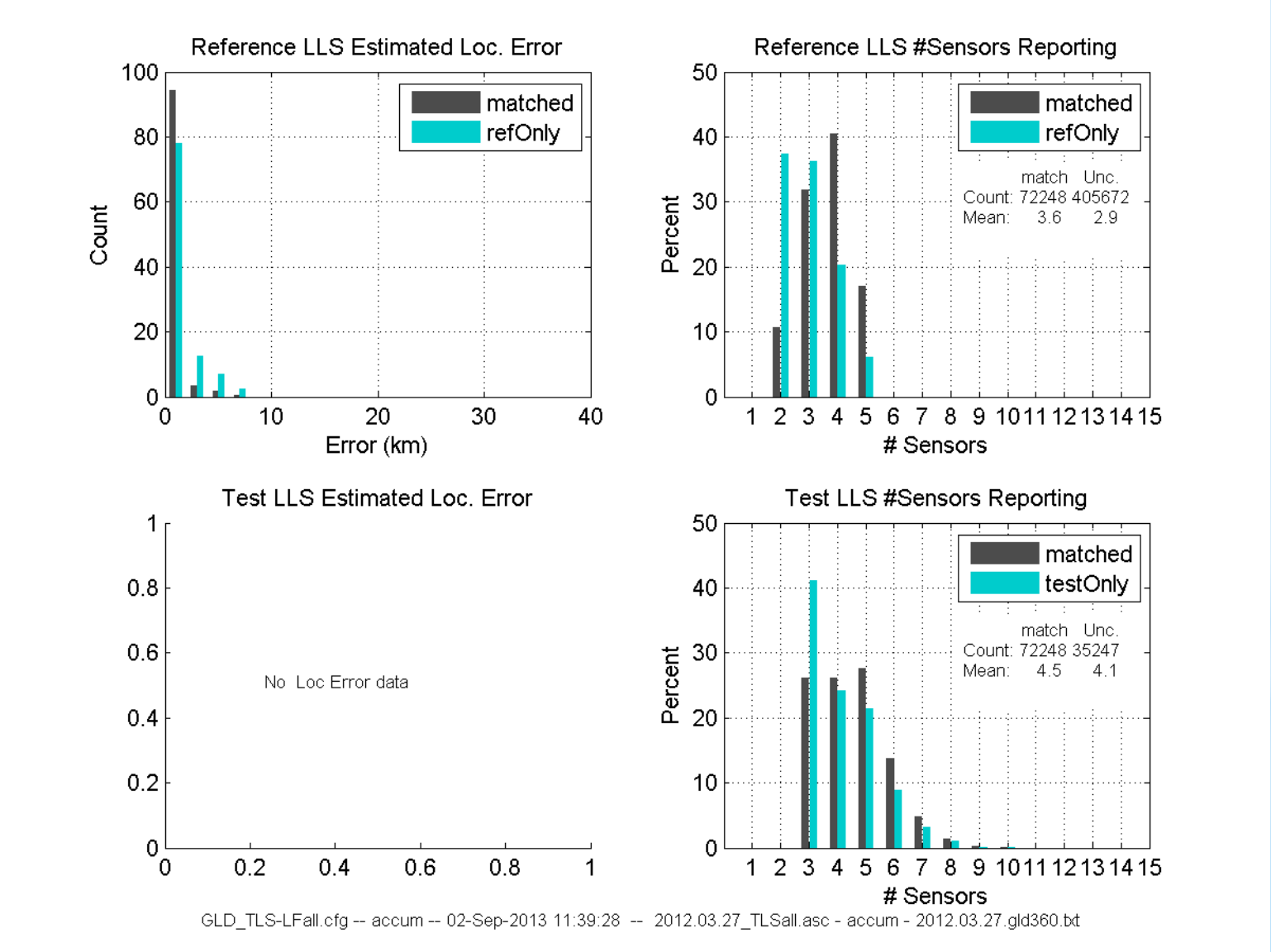
	Test CG	Test CLD
Ref. CG	057016	000000
Ref. CLD	015232	000000

2635 rej. for separation distance 0 rej. for Type mis-match

* Sheet 2 - CHUVA TLS-all vs. GLD360



* Sheet 3 - CHUVA TLS-all vs. GLD360



* 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)*

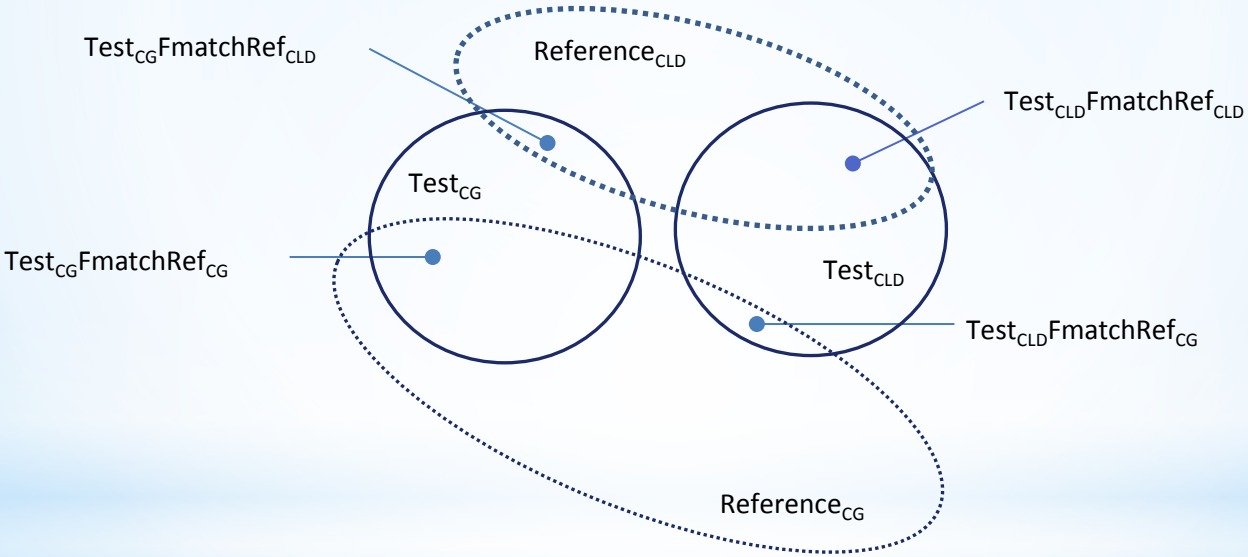
* Flash Analysis Overview

* 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

* 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)

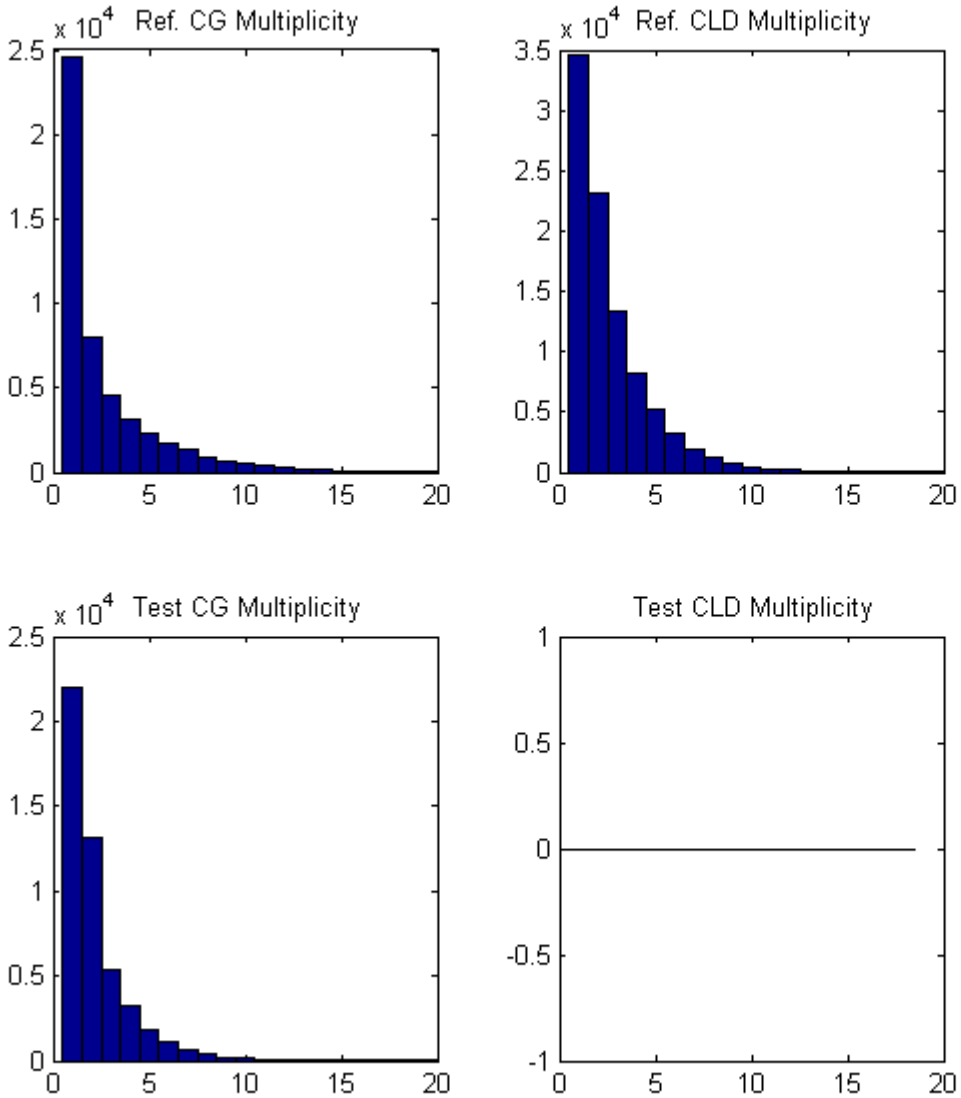


Examples:

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

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

* Flash - CHUVA TLS-all vs. GLD360



Flash Analysis

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

---Type---	Flashes	Mult
CG	048795	2.70
CLD	092969	2.65
CLD-in-CG	064391	1.32
PreCld	035330	

Flash Detection Efficiency

refCG	testCG	refCLD	testCLD	refAll	testAll
76.1	44.6	NaN	8.2	76.1	20.7

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

---Type---	Flashes	Mult
CG	048352	2.22
CLD	000000	NaN
CLD-in-CG	000000	0.00
PreCld	000000	

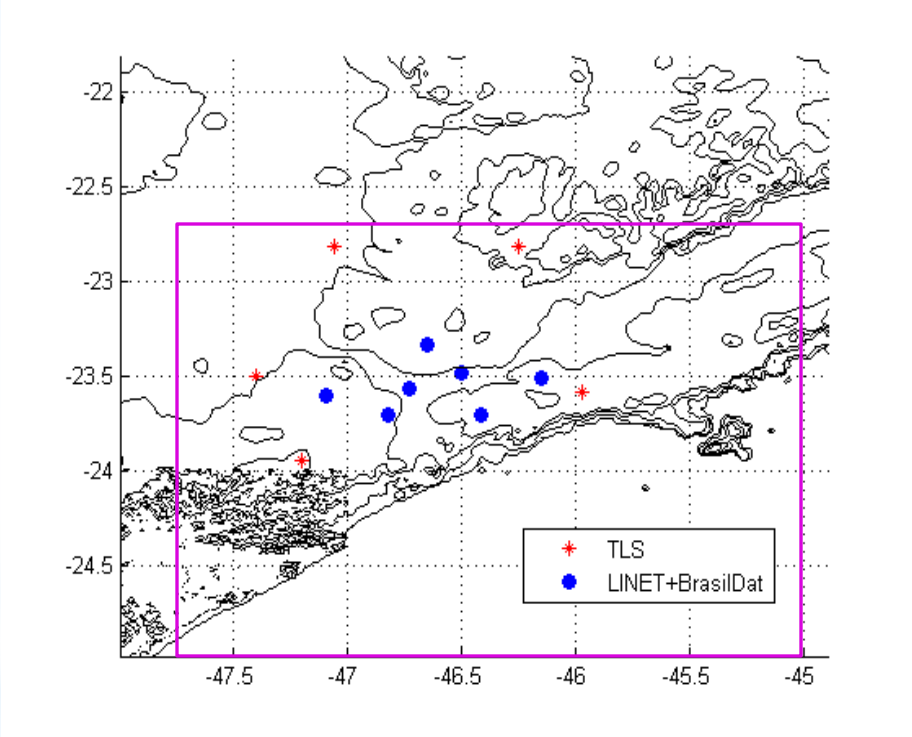
GLD_TLS-LFall.cfg -- accum -- 02-Sep-2013 11:39:28 -- 2012.03.27_TLSall.asc - accum - 2012.03.27.gld360.txt

* LIS-referenced DE: Summary Statistics

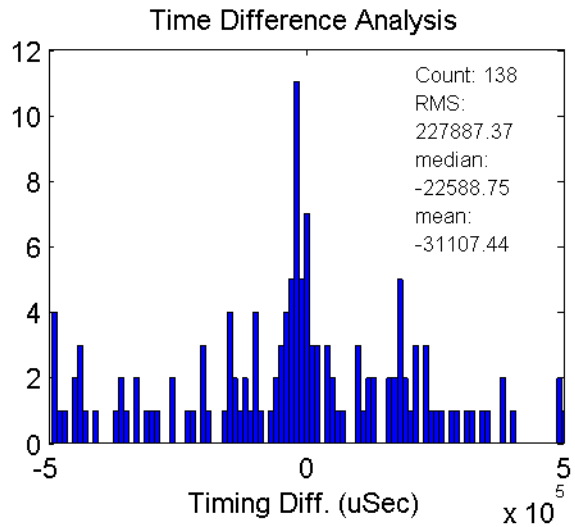
* Simple question: When LIS saw something, did others see it?
* METHOD:
  * Selected a "common" (small) region and time period
    * Region determined by LINET
    * Time period limit defined by TLS200
      * January 1 through March 27, 2012
        * Note: LINET is compromised during these times
    * Total Groups/Flashes were ~2900/300 in 13 overpasses
  * Computed group-referenced DE and Flash-referenced DE
    * Produced 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)

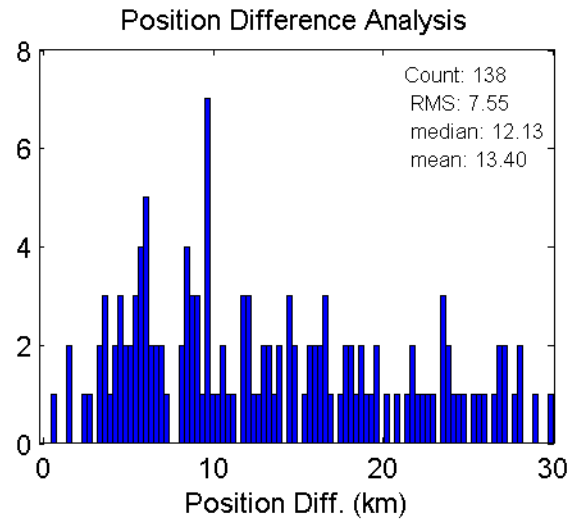
*Selection of the Analysis Domain

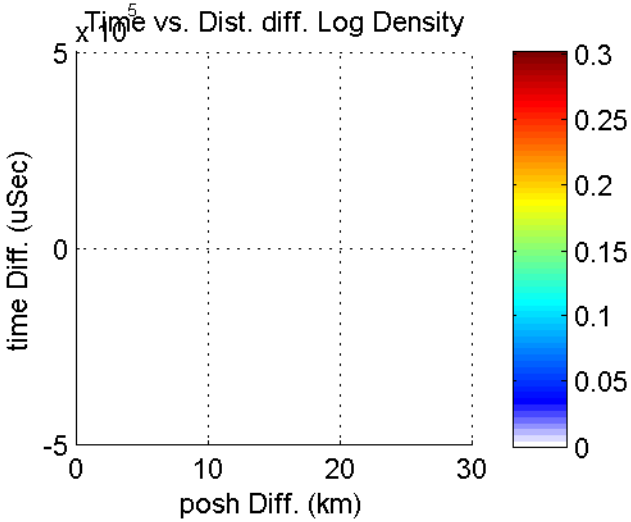
* Smaller domain would not have enough LIS flashes (< 300)
* The domain is quite large for LINET
  * confirmed that the LINET pulse/stroke DE, relative to TLS-LF-all, was not compromised over this domain



* Sheet 1 - LIS Groups vs. GLD360







LIS_GLD.cfg -- accum -- 19-Sep-2013 16:30:44
Reference File: LIS-LMA-2012-01-01_15_01_16_01330_LIS.txt
Test File: 2012.01.01.gld360.txt

Network	#CG / DE	#CLD / DE	#Corr / DE
Ref:	2919 / (0.5)	0 / (NaN)	138 / (0.5)
Test:	29019 / (4.7)	0 / (NaN)	138 / (4.7)

Classification Table:

	Test CG	Test CLD
Ref. CG	000138	000000
Ref. CLD	000000	000000

17310 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	2.9/2.5	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

*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?

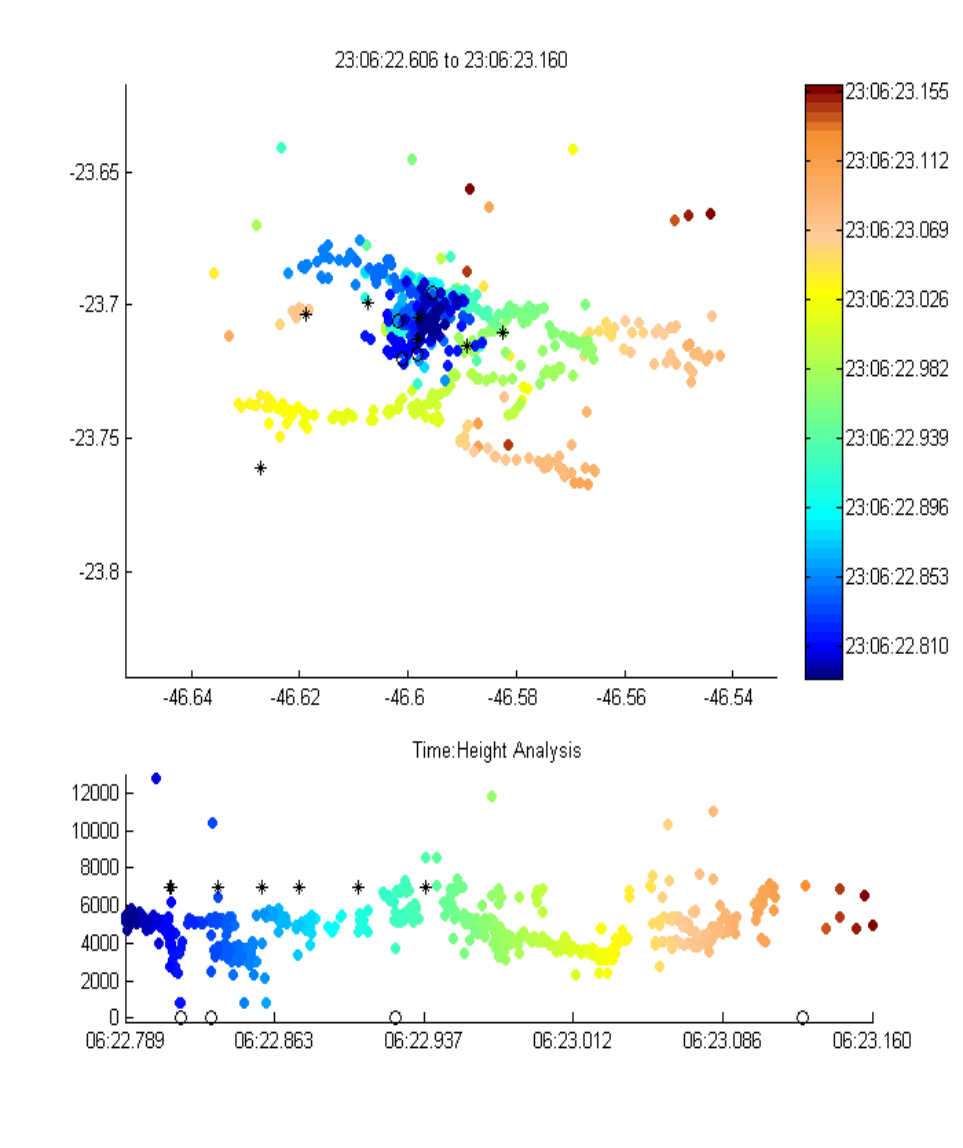
* BrasilDat
  * Typically, only 1-2 of the 7 “special” sites were operational, and the network was just being calibrated. The network is now working much better than it was during the CHUVA campaign. (the ~100 km baseline in the previous slide reflected the “functional” baseline during this study)

* 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

*Where *(in space)* are the VLF/LF cloud pulses detected?

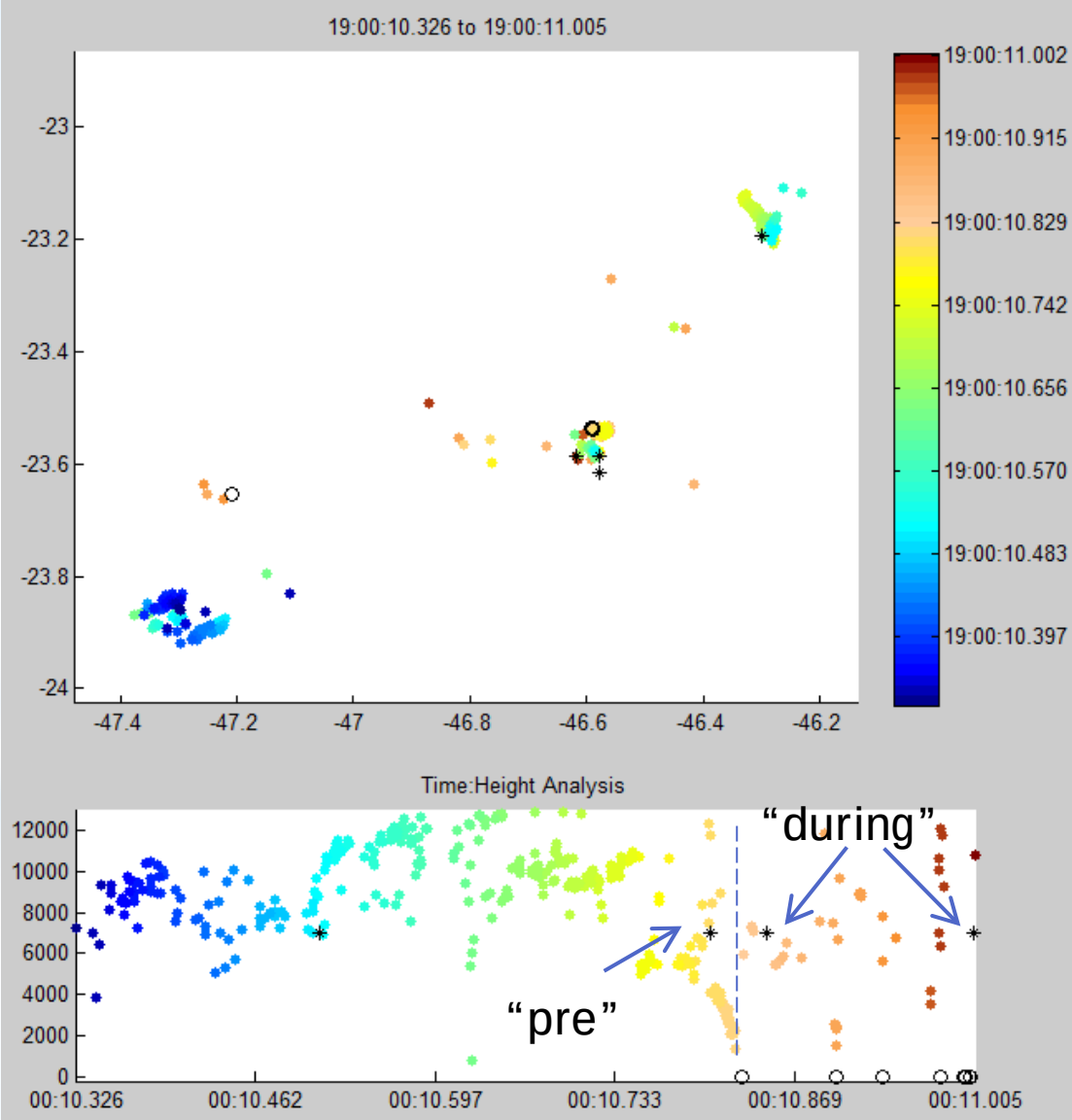
* In most cases, they cluster near the flash origin



*Where *(in time)* are the LLS cloud pulses detected?

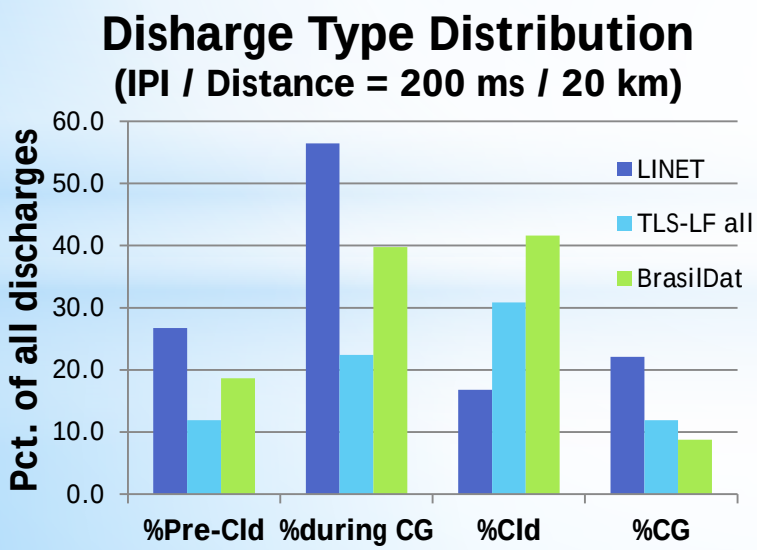
* Are they part of a cloud flash?

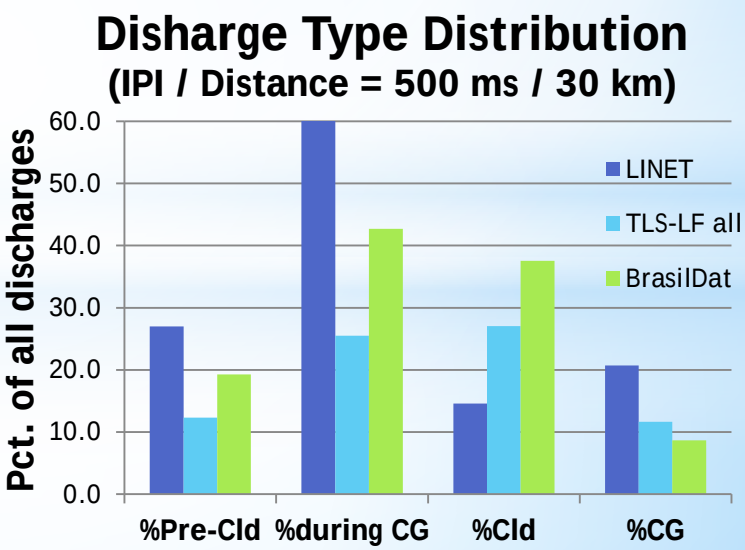
*Are they part of a CG flash?



*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





* Summary / Comments

* LLS's Type Classification is a Practical Problem

  * Either different LLS's report different clouds pulses (CG-related or cloud-flash-related), or there are significant type-classification errors

  * If an LLS dominantly reports CG-related cloud pulses, then its total CG+CLD discharge rate is not representative of the true total-lightning flash rate

*Possible Future Directions

* Extend the long-range LLS analysis of LIS DE to larger "land" and "ocean" domains, to see how well the do in areas where other land-based networks cannot provide proxy or validation data (if nor already done by Scott R.)

* Try to use above results to allow statistical up-scaling of LLS data for proxy product generation and pre-calibration of post-launch validation systems (similar to DLR activities)

* Formalize correlation between LLS estimated peak current (CG and CLD pulses) and LIS group radiance and group area (similar to DLR activities)