

Terrestrial Gamma Flashes at Ground Level (TGEs) TETRA II



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TGFs seen by multiple detectors, mainly with +IC lightning
→ When threshold is decreased or trigger improved, we see more events.

If one looks at small events, will there be many more?
To do this, one cannot be at 500 km altitude.
Need to be close (in the atmosphere, on the ground)

Mountain-top detector in NM observed three msec bursts of X-rays associated with -CG lightning

One +IC event seen on aircraft (ADELE) at distance ~10 km

Two events seen at ICLRT ground-based array in Florida
One due to triggered lightning
One due to natural (-CG) lightning

Aragats, Japan: ground enhancements with IC lightning
>7 MeV on timescales μ sec, tens of minutes

TGF and Energetic Thunderstorm Rooftop Array (TETRA)

Ground array – 4 detector boxes of 3 NaI scintillators on rooftops on LSU campus

- 5" (12.7cm) Photomultiplier tube (PMT)
- Acrylic light guide
- 8 in x 8 in x $\frac{1}{4}$ in NaI scintillator (20.32cm x 20.32cm x .6cm)

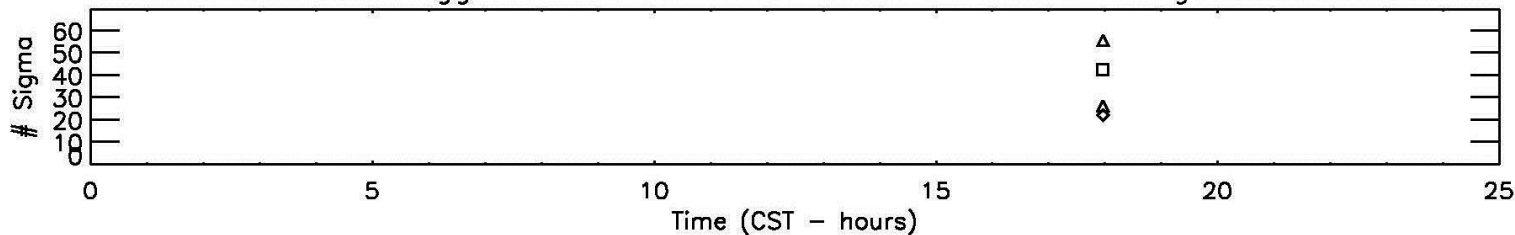


TETRA Daily Report for 2011-08-18

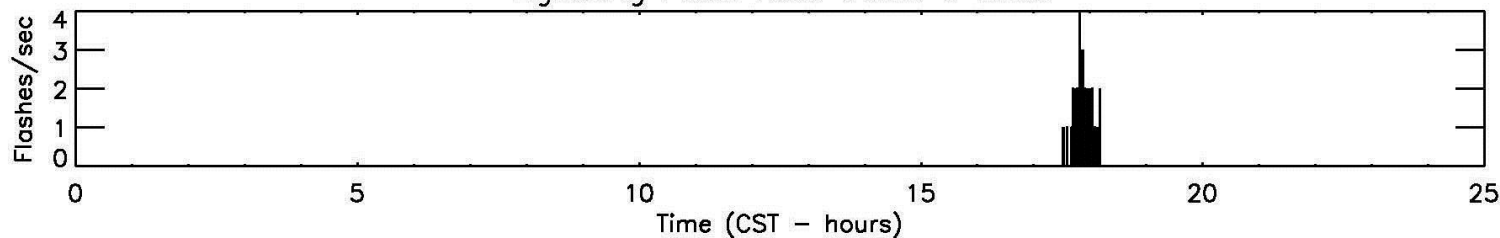
Diamond - Box 1
Plus Sign - Box 2

Triangle - Box 3
Square - Box 4

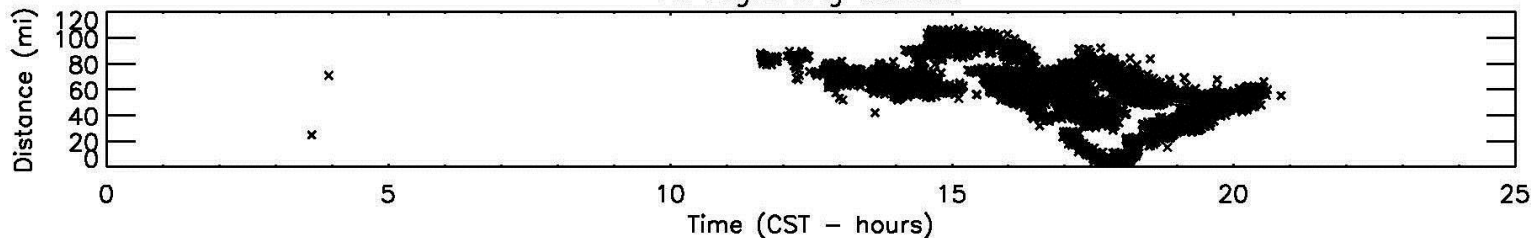
Triggers Detected Above Threshold for 2ms Binning



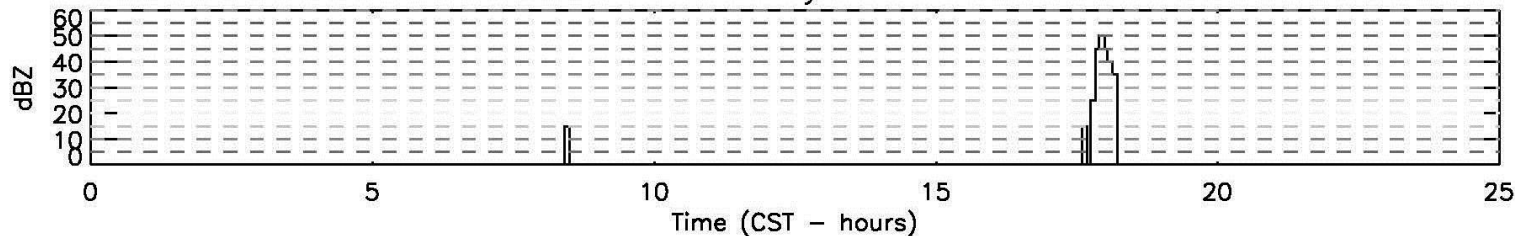
Lightning Flash Rate Within 5 Miles



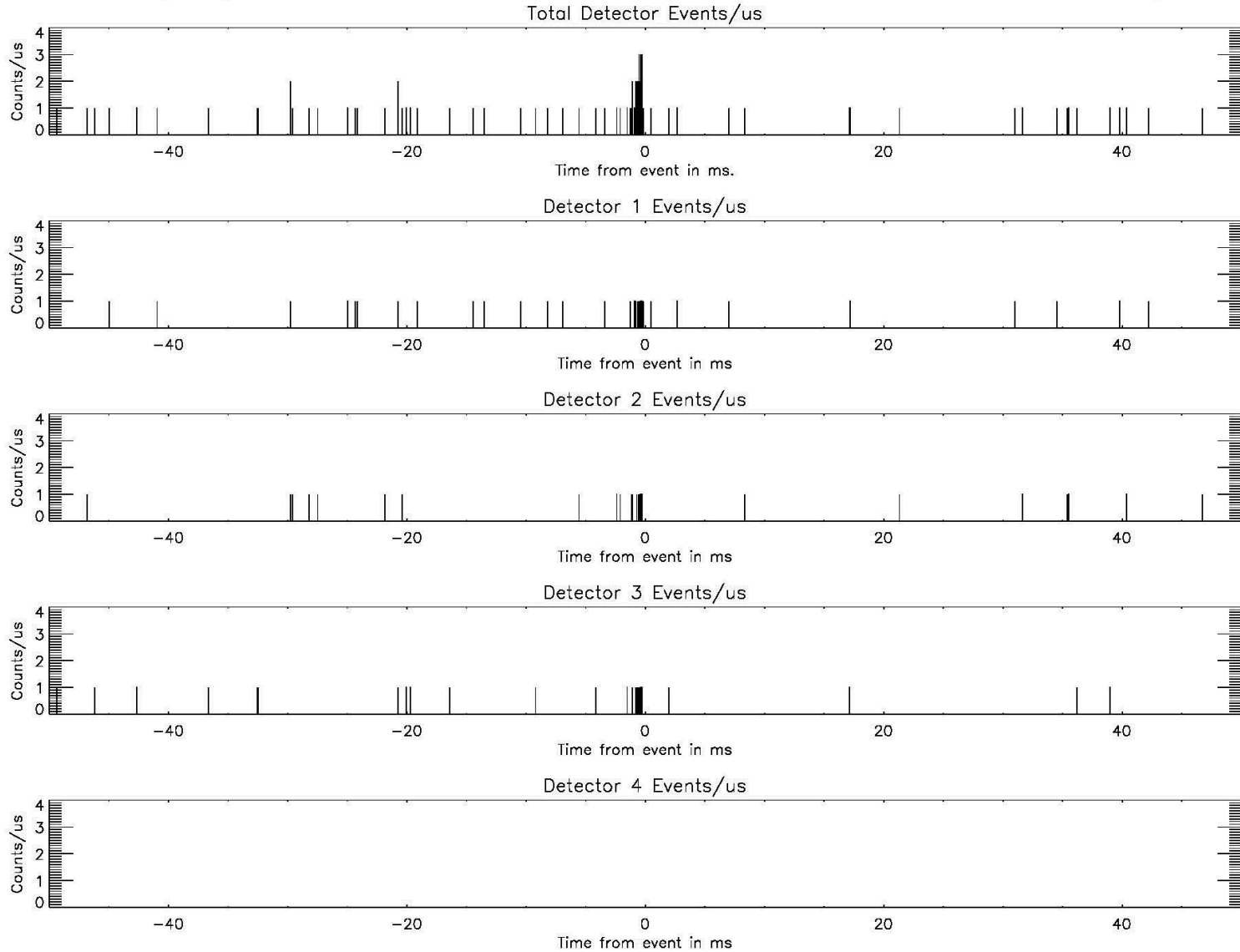
All Lightning Strikes

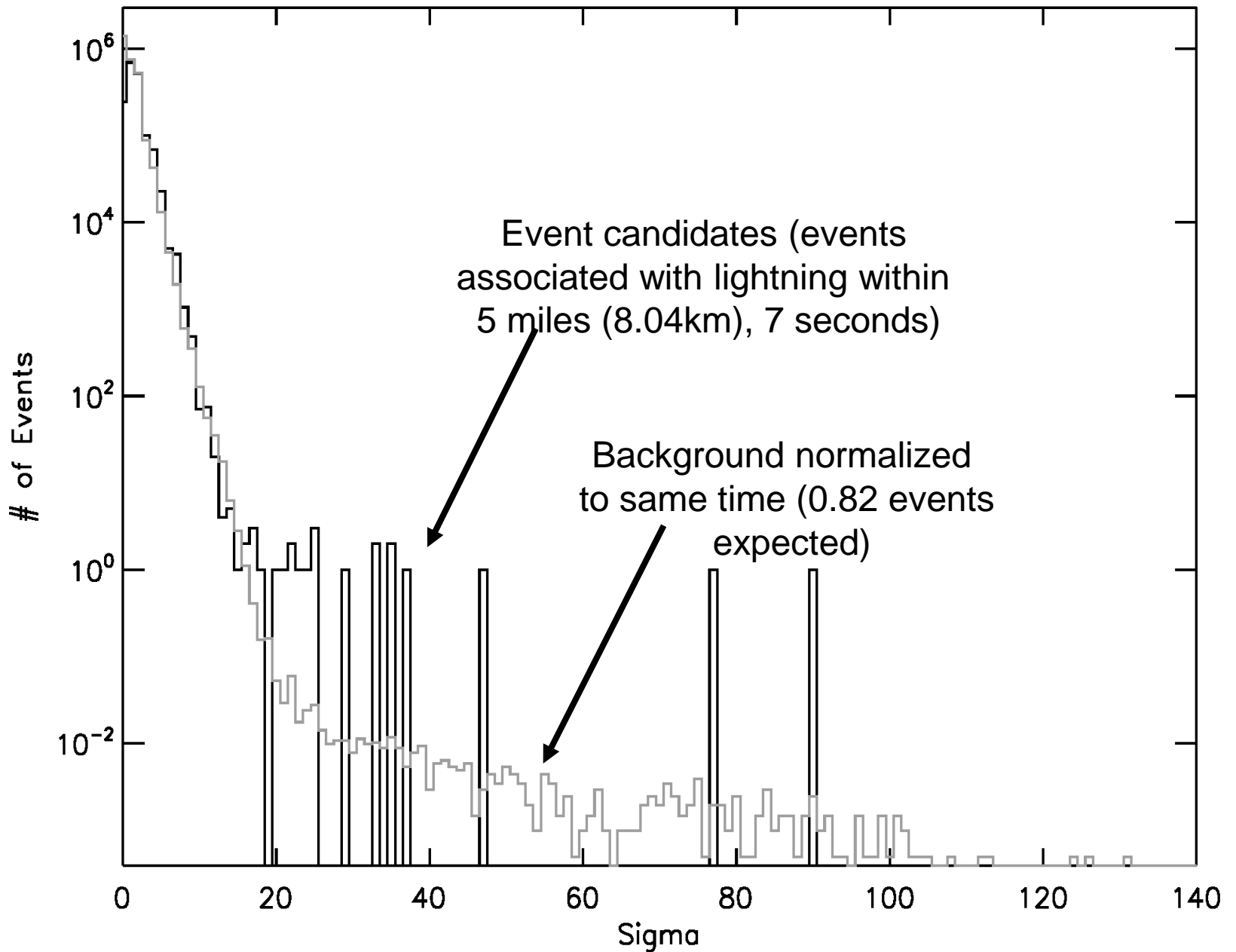


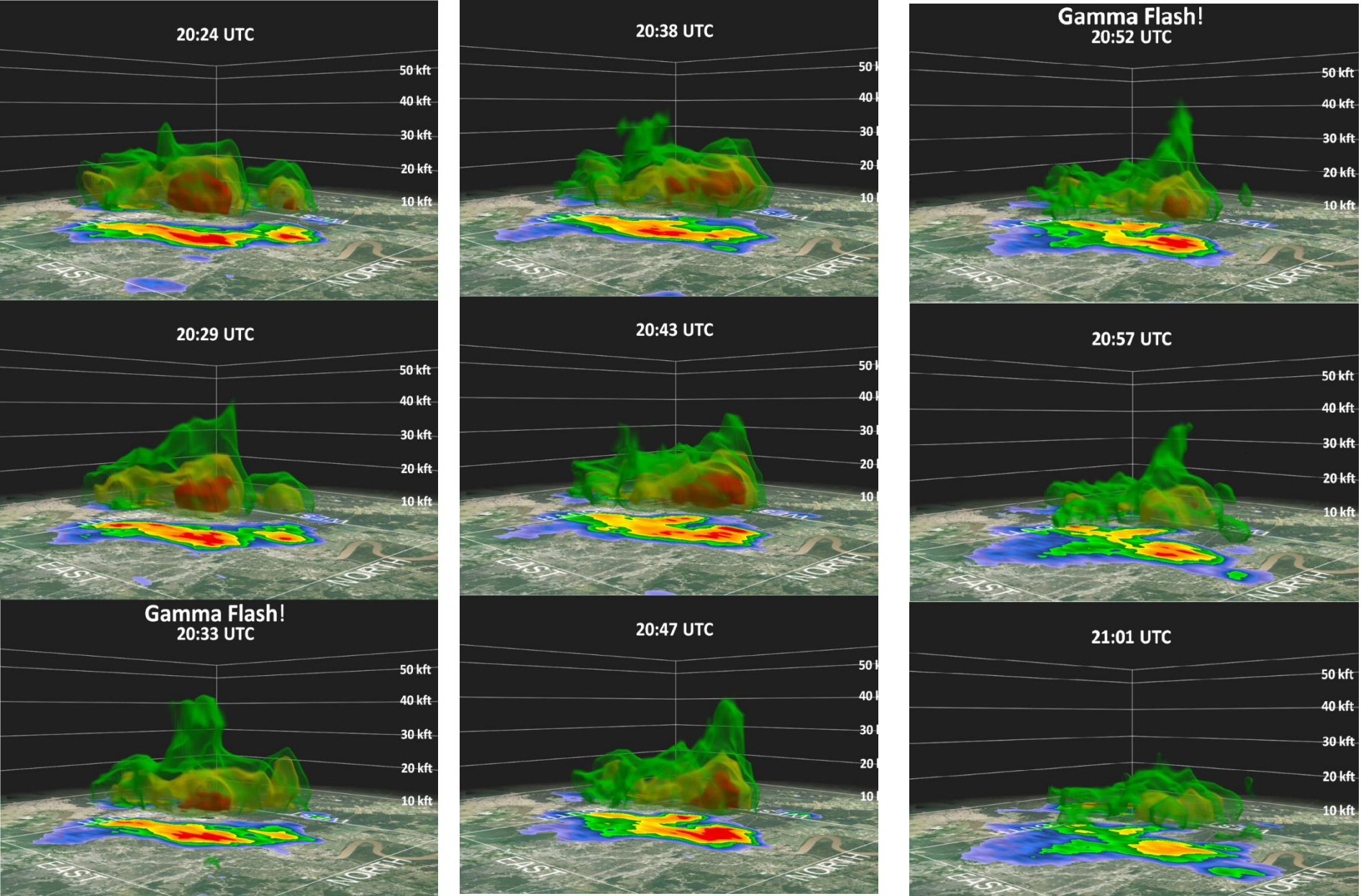
Cloud Density Overhead



Box 3 Events/us for 100ms Window Centered on 2013-05-10-03-55-05-398 (91 Events Found).
Closest lightning strike was -67 ms and 0.7609 miles away with peak current of -38.8 kA. 37.4 ns timing error.







June 22, 2013

40kft ~ 12km

Ringuette, Rebecca et al. "Gamma rays associated with Nearby Thunderstorms at Ground Level." *XV International Conference on Atmospheric Electricity*, 15-20 June 2014, Norman, Oklahoma, U.S.A.

Ringuette, Rebecca et al. "TETRA Observation of Gamma-Rays at Ground Level Associated with Nearby Thunderstorms." *Journal of Geophysical Research. Space Physics* 118.12 (2013): 7841–7849. *PMC*.

Date	Trigger Time (CST) (hh:mm:ss)	Timing Error (μ s)	Max Lightning Rate within 5mi. (sec^{-1})	Cloud Density (dBZ)	Storm Type	# Flashes within 5mi. and 5min.	Trigger-Lightning Difference (ms)	Lightning Distance (mi)	Lightning Current (kA)	T ₉₀ Event Duration (μ s)	Total γ Rays Detected	Total Energy (MeV)	σ Above Mean	Probability of CEC
31 Jul 2011	16:21:44.976	3950	2	45	Coastal	12	-6	1.4	-43.6	702	19	8.8	25.1	1.7E-06
31 Jul 2011	16:21:45.300	3950	2	45	Coastal	12	-4	1.8	-29.1	1326	23	9.6	25.1	1.7E-06
18 Aug 2011	17:57:38.986	3449	4	50	Coastal	40	6741	1.3	-23.4	1318	38	16.5	22.4	1.2E-13
24 Feb 2011	23:11:15.787	2328	3	45	Front	1	-6	2.9	-20.9	953	20	1.7	24.6	-
29 Jul 2011	10:38:58.932	775	6	45	Coastal	42	5	0.4	-57.7	153	8	4.8	22.6	-
18 Aug 2011	17:57:39.202	3196	4	50	Coastal	40	6525	1.3	-23.4	24	7	3.6	23.8	-
12 Mar 2012	11:30:16.500	1676	6	45	Front	4	5	1.6	-81.3	1997	7	3.2	20.7	-
2 Apr 2012	12:29:30.554	1980	3	50	Coastal	8	6	0.6	-29.9	464	21	15.8	90.0	-
4 Apr 2012	02:49:21.900	1240	5	55	Front	21	-3	1.9	-158.4	515	24	21.3	77.2	-
5 Aug 2012	14:43:35.661	-	7	40	Coastal	16	-849	0.6	-56.5	392	11	6.1	35.3	-
6 Aug 2012	19:17:33.359	-	5	50	Coastal	1	1017	0.8	-23.1	465	10	4.5	21.8	-
9 Aug 2012	15:27:29.804	4832	4	50	Front	21	2	0.4	-27.8	2412	12	2.9	25.6	-
9 Aug 2012	15:28:36.070	4832	4	50	Front	27	80	0.9	-36.7	4217	24	7.4	35.7	-
9 Aug 2012	15:28:36.560	4832	4	50	Front	27	2	0.8	-19.2	146	12	8.0	29.7	-
6 Jun 2012	15:37:31	-	6	55	Coastal	40	-	-	-	759	36	17.5	85.3	-
6 Jun 2012	15:44:18	-	6	55	Coastal	16	-	-	-	609	14	8.5	46.9	-
6 Jun 2012	19:29:43	-	6	55	Coastal	33	-	-	-	2376	24	9.7	51.9	-
6 Jun 2012	19:31:21	-	6	55	Coastal	19	-	-	-	746	31	16.2	45.6	-
6 Jun 2012	19:36:41	-	6	55	Coastal	18	-	-	-	604	28	21.1	57.7	-
14 Apr 2013	01:26:02.390	0.037	4	45	Coastal	2	-493	0.7	-46.9	1552	9	3.9	51.4	-
24 Apr 2013	07:11:37.894	0.024	5	50	Front	24	6595	1.9	-64.8	616	7	1.6	25.6	-
10 May 2013	03:51:57.412	0.034	5	55	Front	166	969	1.3	-23.9	1032	29	-	101.3	-
10 May 2013	03:51:58.116	0.047	5	55	Front	163	265	1.3	-23.9	80	6	2.1	25.2	-
22 Jun 2013	14:31:28.794	0.058	5	50	Coastal	7	-292	1.7	-33.8	159	8	1.9	25.8	-
22 Jun 2013	14:52:49.063	0.043	5	50	Coastal	6	199	1.3	-48.9	1757	15	5.6	50.4	-
29 Jun 2013	04:24:11.550	0.038	4	40	Front	17	-169	1.7	-32.9	732	14	7.0	89.7	-
29 Jun 2013	04:24:11.614	0.038	4	40	Front	17	-233	1.7	-32.9	164	4	3.0	31.6	-
13 Sep 2013	18:11:13.263	0.019	5	50	Coastal	39	403	1.4	-35.3	1539	18	6.2	40.9	-

Next step – TETRA-II

Can we measure abundant small TGFs close up with better statistics →

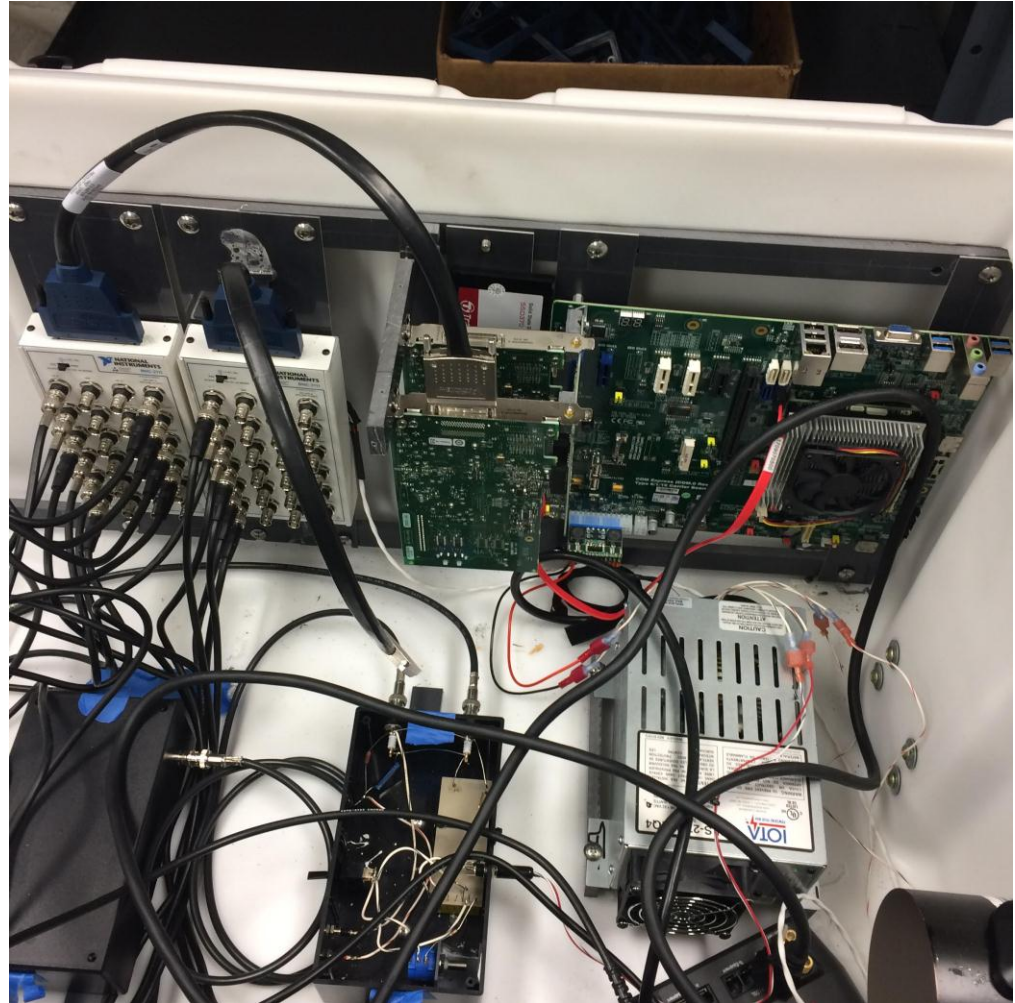
- Measure intensity distribution
- Measure energy spectrum
- Measure distance to events accurately
- Monitor lightning more efficiently
- Correlate radiation with meteorological conditions
- Observe storms simultaneously from ground and space

- 120 BGO scintillators 1" × 1" × 10" (2.54cm x 2.54cm x 20.54cm) viewed by 1.5" (3.81cm) PMT at each end. PMTs are spring-mounted into PVC housings. Six BGO-PMT assemblies are mounted in a single detector box
- PMTs read out by National Instruments PCIe 6351 high speed data acquisition (1 Msample/ sec) cards, transmitted to server at LSU

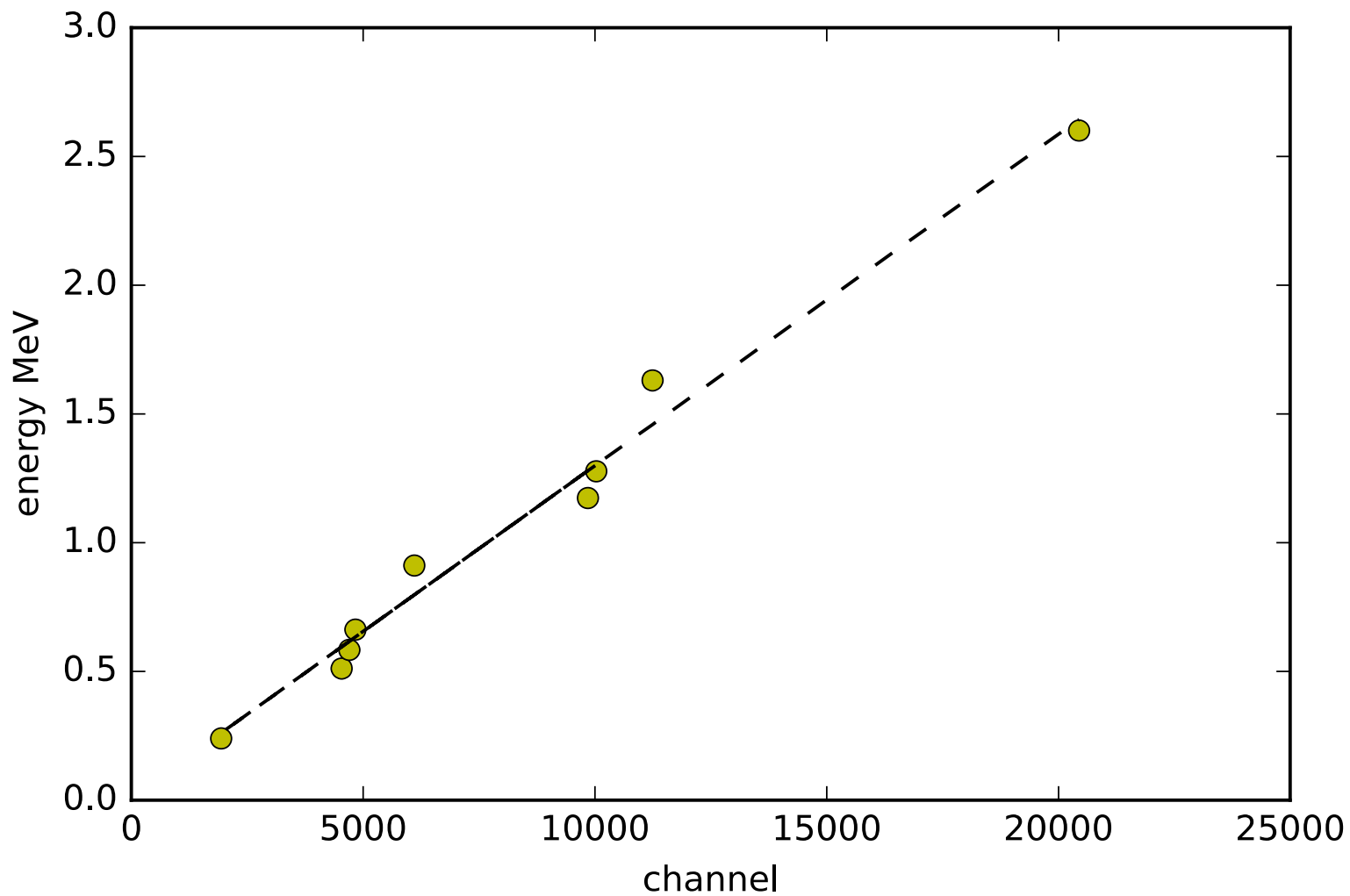


Data Collection

- Front end board amplifies and holds trigger peak for 13 μ sec
- Software written in labview
- Outputs 3 files with timestamp information, 1 with adc values

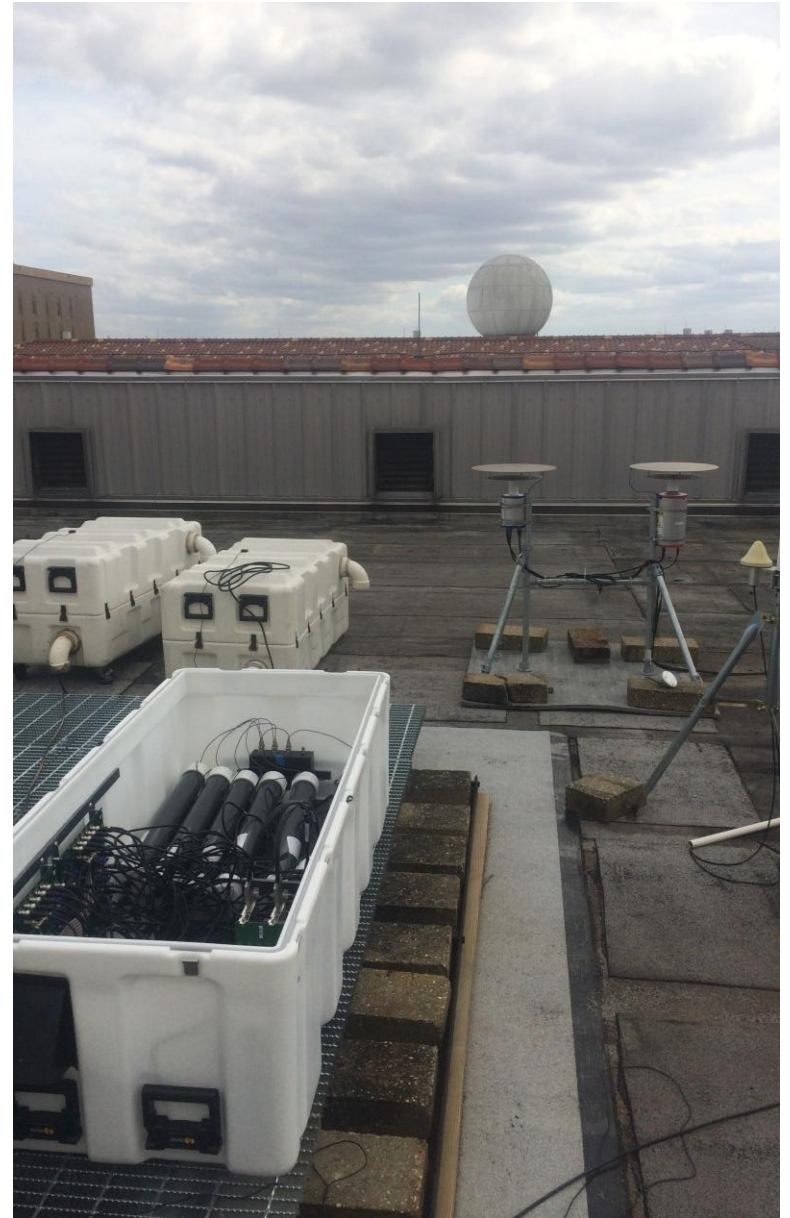
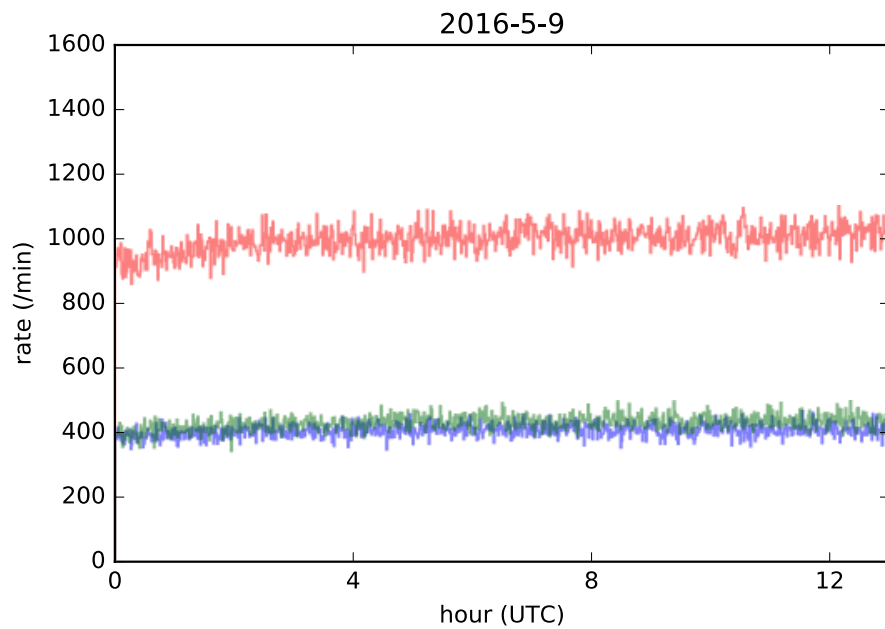


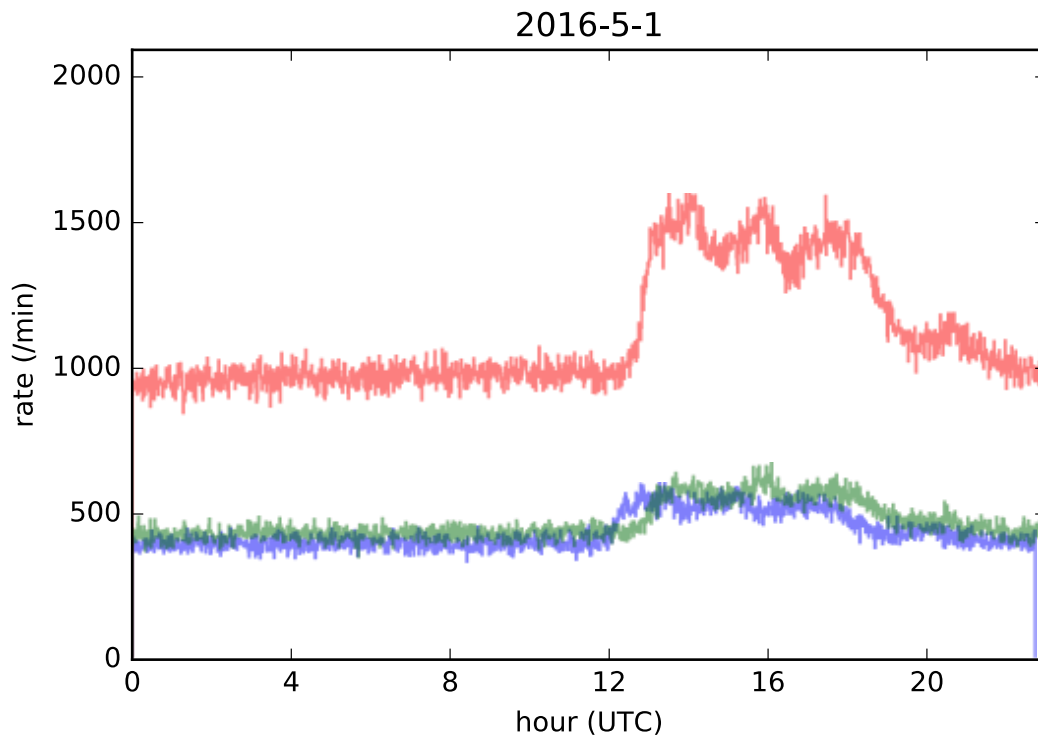
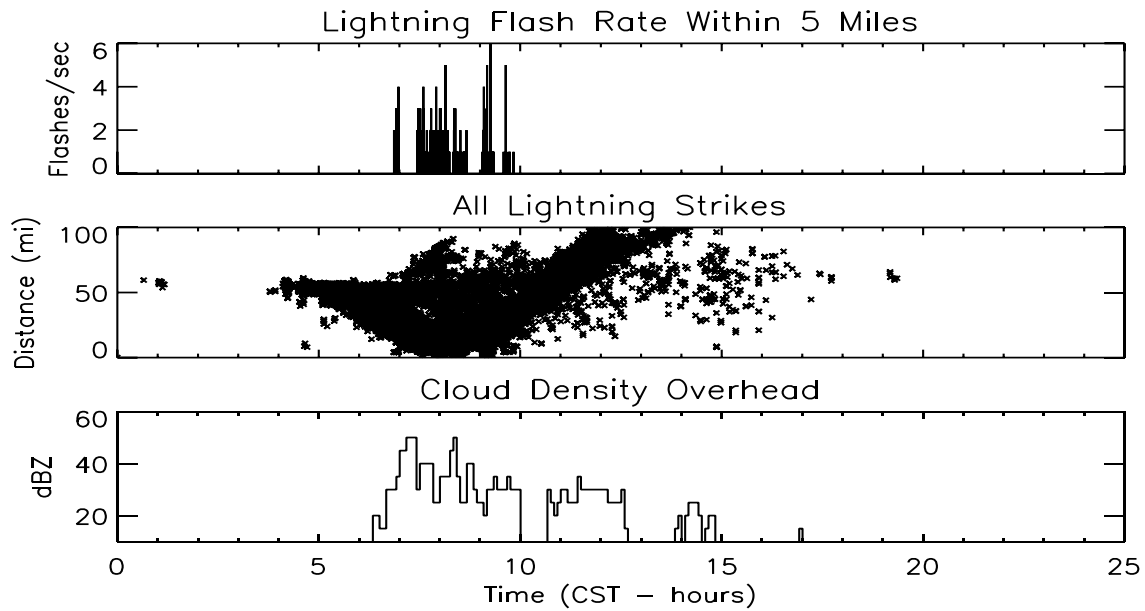
Calibration



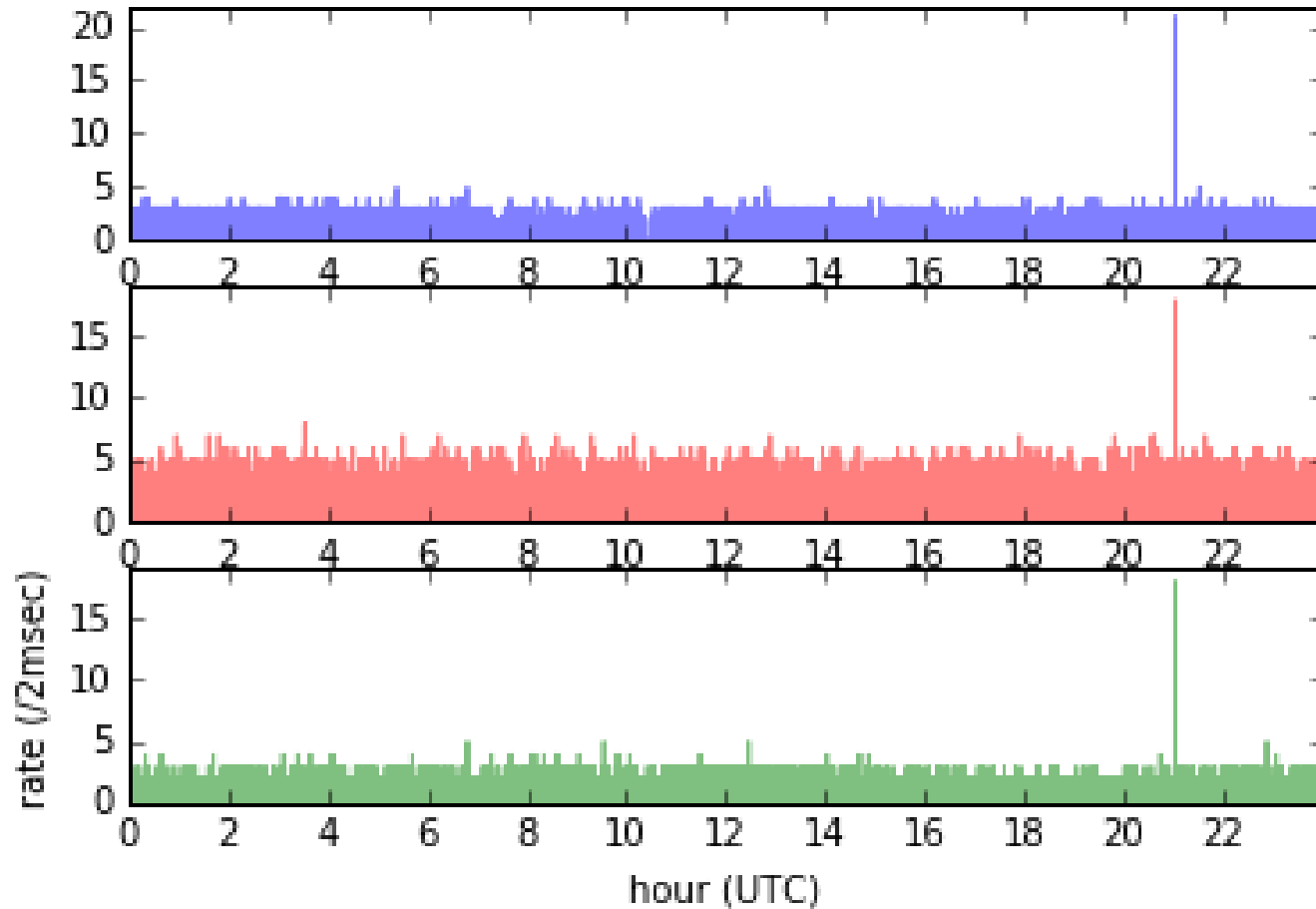
LSU

- 2 boxes fully assembled and taking data

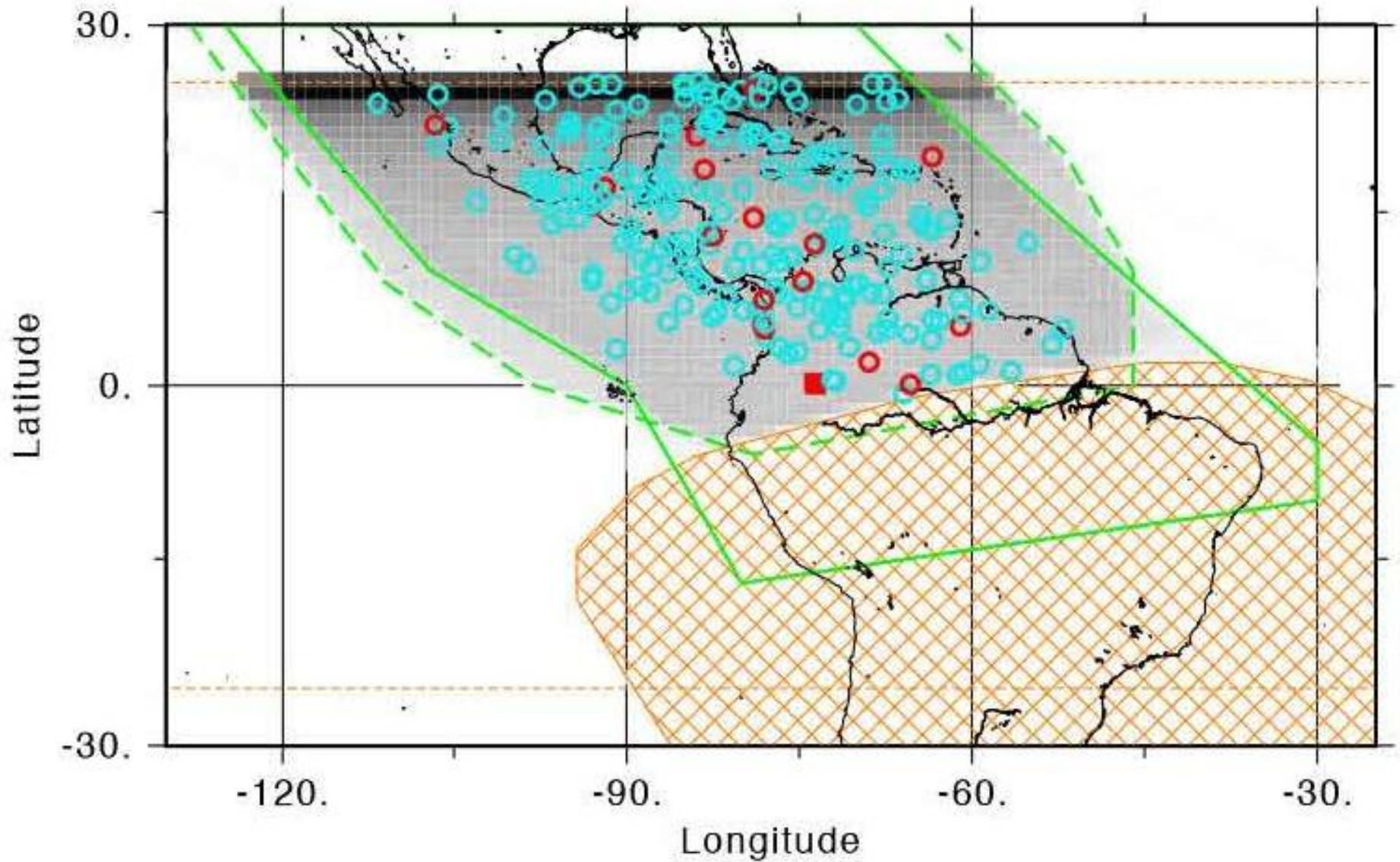




Event Candidate August 24, 2016



Recent map by GBM on Fermi of TGFs in Americas



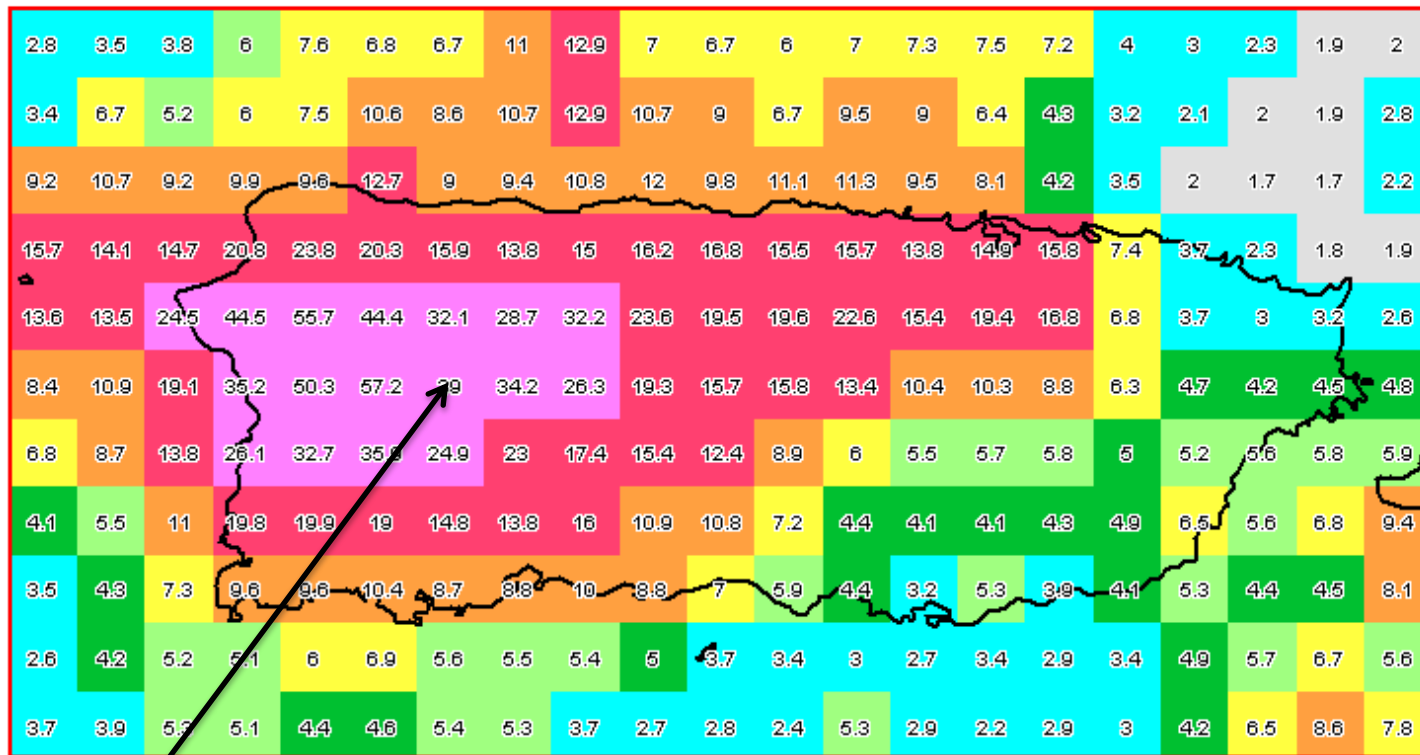
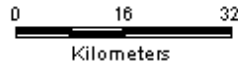
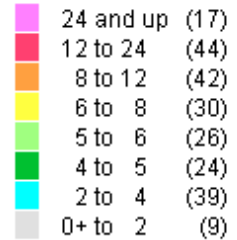
TETRA - II

- **Lightning density 2-4/km²/month in Baton Rouge compared to 4-8/km²/month in NW Puerto Rico, 8-16/km²/month in Jamaica**
- **December 2015 - Constructed expanded TGF array in Puerto Rico**
- **60 Bismuth Germanate (BGO) scintillators will provide x5 statistics up to 10 MeV**
- **Instrument arrays with directional lightning antennas to determine height and distance**
- **Monitor meteorological conditions**
- **Locate TETRA-II beneath satellite tracks to enable simultaneous space-ground observations**

GLD360 data; 2013
10 km x 10 km density grid
Lat 17.75N - 18.75N
Lon 67.5W - 65.5W

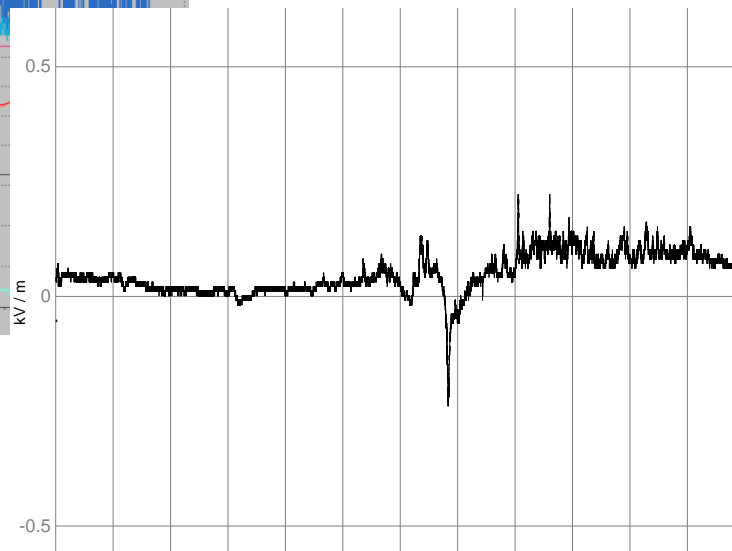
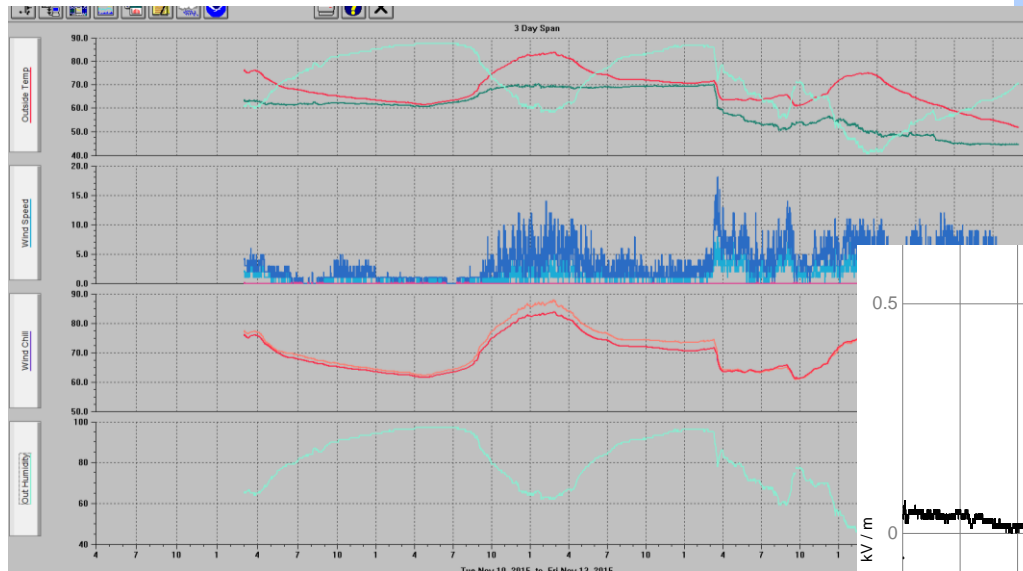
TETRA II Location

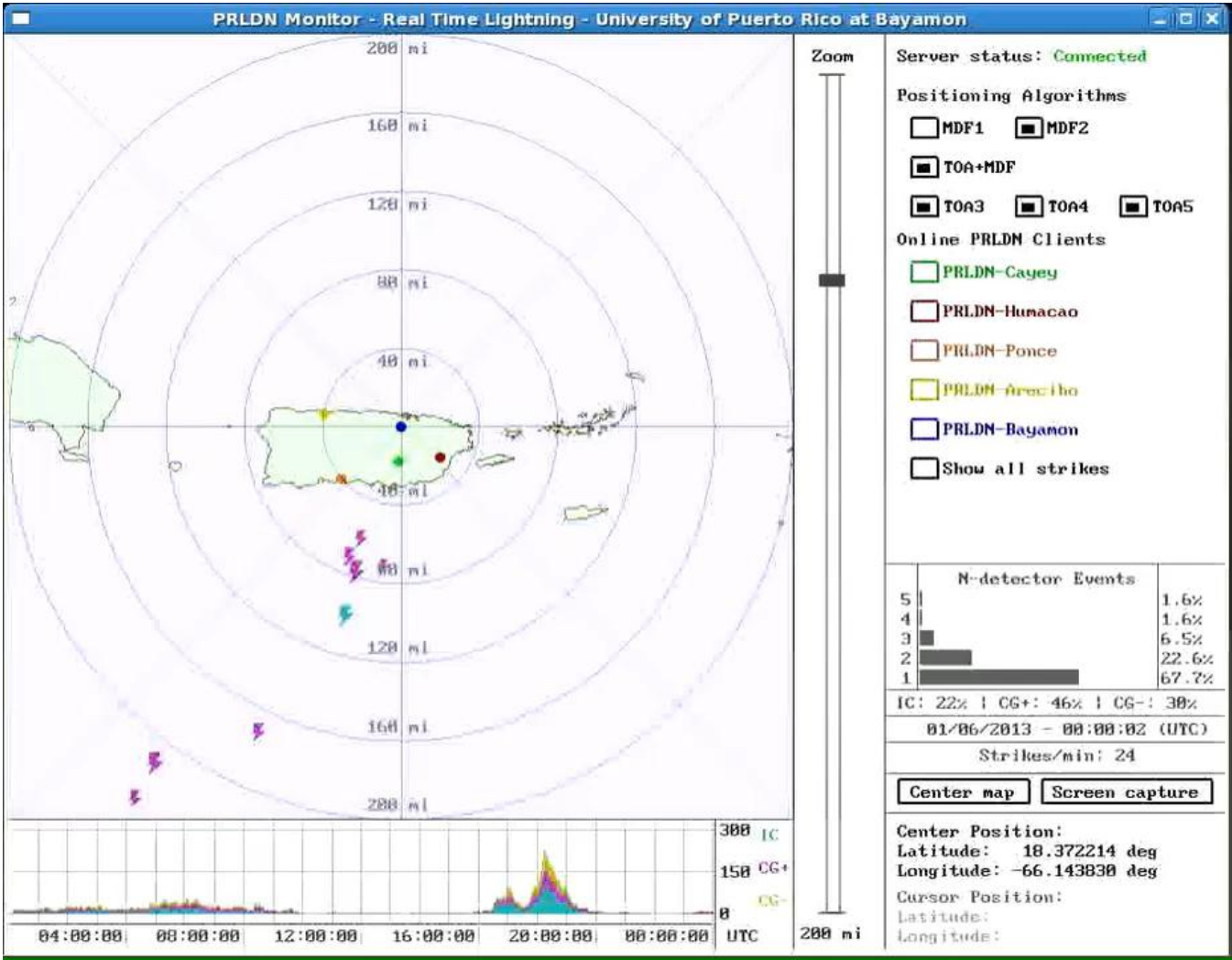
GLD360 data
strokes/sq km/yr



**Utuado,
Puerto Rico**

- Boltek lightning detectors
- Electric field monitor
- Weather station





PRLDN Monitor - Real Time Lightning - University of Puerto Rico at Bayamon

Server status: **Connected**

Positioning Algorithms

MDF1 MDF2

TOA+MDF

TOA3 TOA4 TOA5

Online PRLDM Clients

PRLDM-Cayey

PRLDM-Humacao

PRLDM-Ponce

PRLDM-Arecibo

PRLDM-Bayamon

Show all strikes

N-detector Events	
5	1.6%
4	1.6%
3	6.5%
2	22.6%
1	67.7%

IC: 22% | CG+: 46% | CG-: 30%

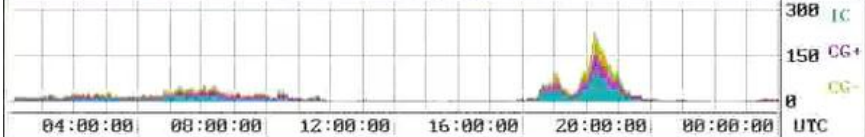
01/06/2013 - 00:00:02 (UTC)

Strikes/min: 24

[Center map](#) [Screen capture](#)

Center Position:
 Latitude: 18.372214 deg
 Longitude: -66.143830 deg

Cursor Position:
 Latitude:
 Longitude:



Utuado

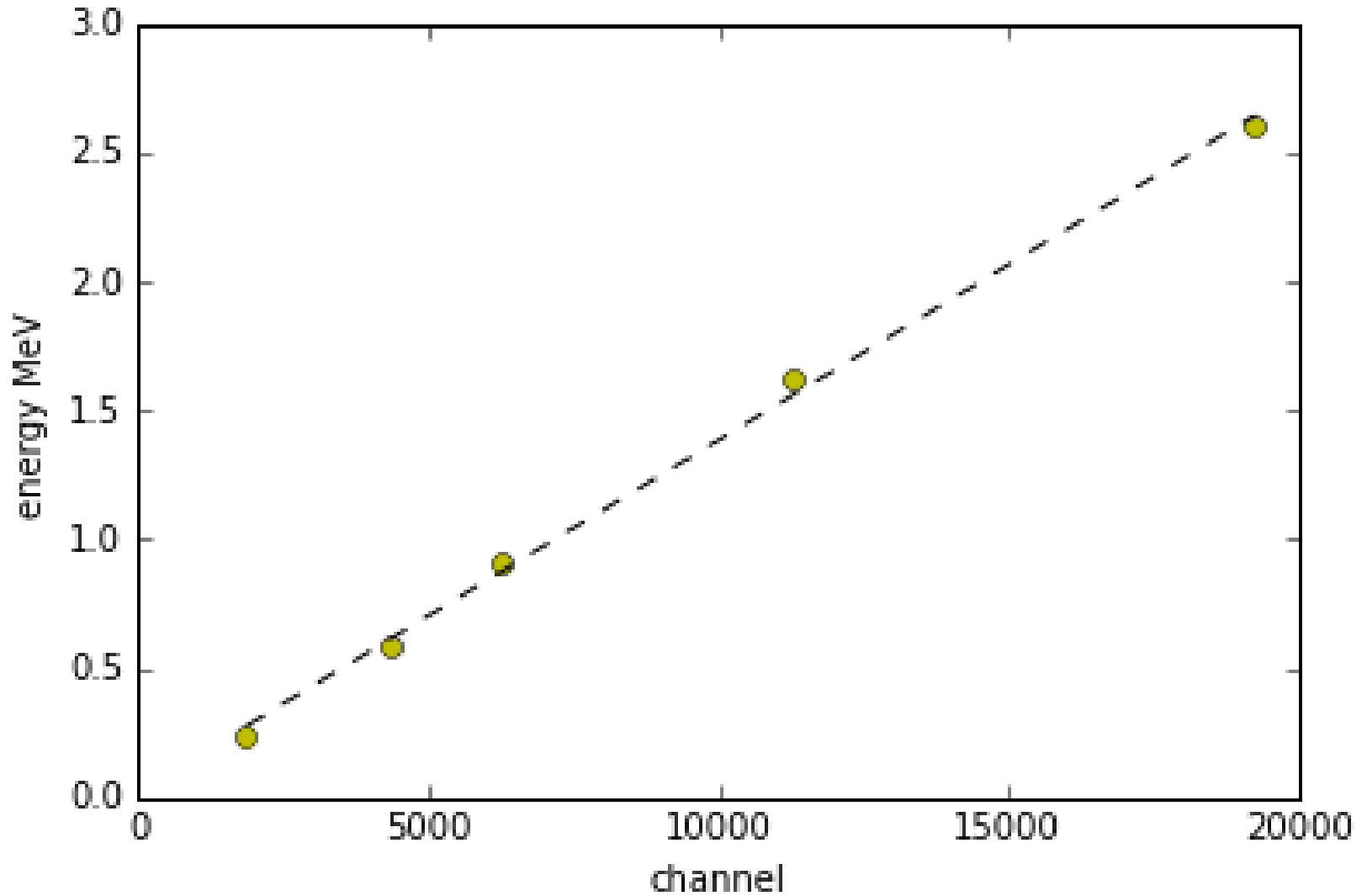




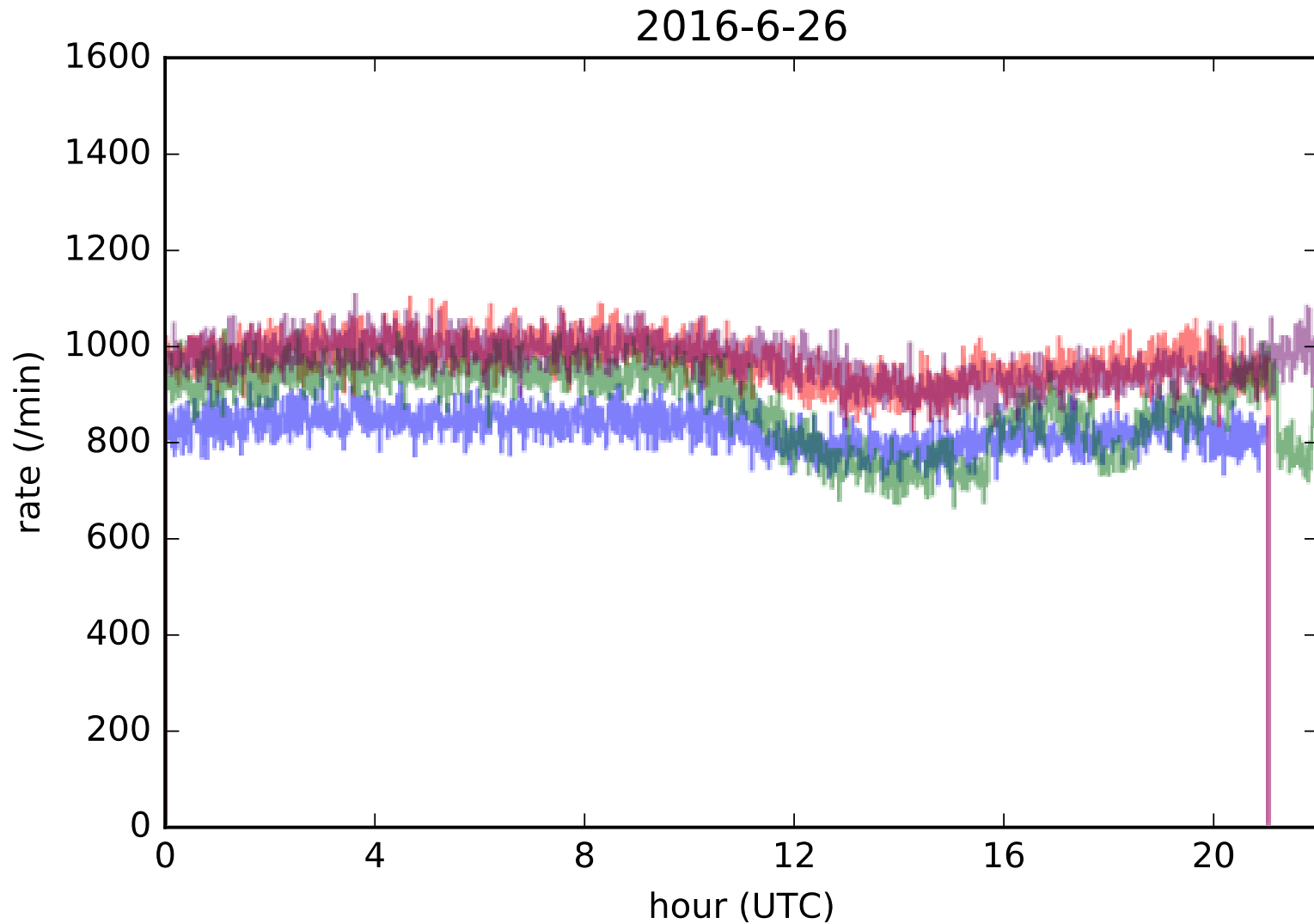




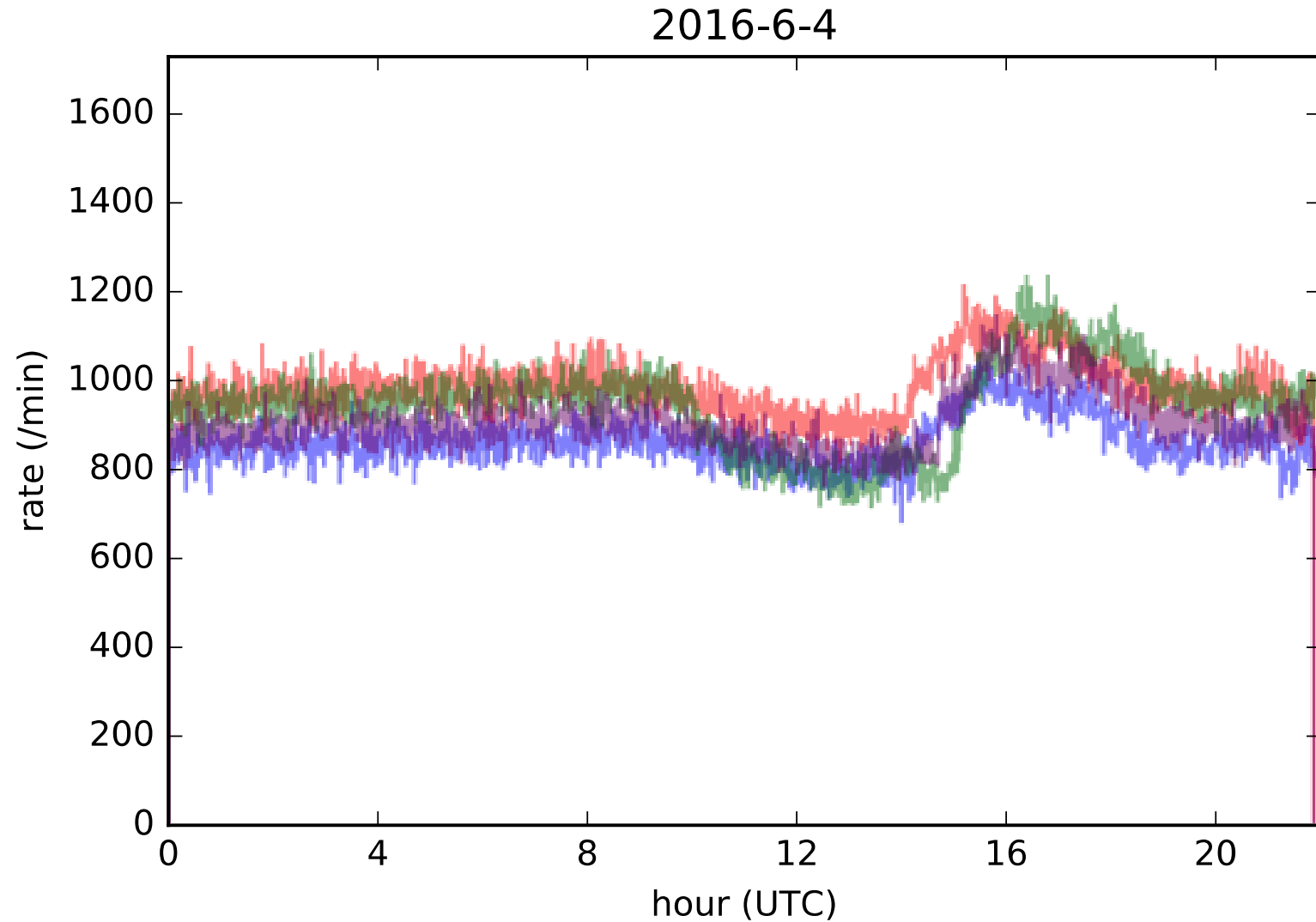
Calibration



June 26, clear day



June 4, afternoon storms



TETRA II Current Status

- 2 Boxes up taking data at LSU
- 10 detectors in Puerto Rico taking data as of August 2016
- In the process of pulling and analyzing data
- Further analysis on bursts in 2ms timescale

Future Plans

- Charged particle detector
- Lead sheet
- Optical camera
- 2 boxes to Huntsville, Alabama
- 6 boxes remaining, P.R.? Panama?
- Installation of weather station and electric field mill at Utuado
- Completion of lightning arrays and comparisons

Will TGFs/TGEs help us to better understand particle acceleration in the most energetic accelerators on Earth, and connections with terrestrial lightning and structure of thunderstorms?



TETRA-II / LA Board of Regents-NSF-NASA EPSCoR participants

LSU –

Faculty: Greg Guzik (EPSCoR PI), Mike Cherry, Greg Stacy, Jill Trepanier

Research staff: C-C Hsu, Doug Smith

Grad students: DJ Pleshinger, Deirdre Smith

Undergrads: Chris Adams, Zach Baum, Jonah Hoffmann, Sarah Morvant, Natalie Zimmer

Xavier –

Faculty: Anderson Sunda-Meya

Undergrads: Ed Brooks, Jazmine Nash, Alex Ward

Southern –

Faculty: Sam Khosravi, Shuju Bai, Greg Stacy

Grad student: Tierra Thomas

Univ. of Puerto Rico–

Faculty: Marc Legault (Bayamón), Reniel Rodriguez (Utuado)

Univ. of the West Indies at Mona –

Faculty: Andre Coy