Geostationary Lightning Mapper for GOES-R and Beyond

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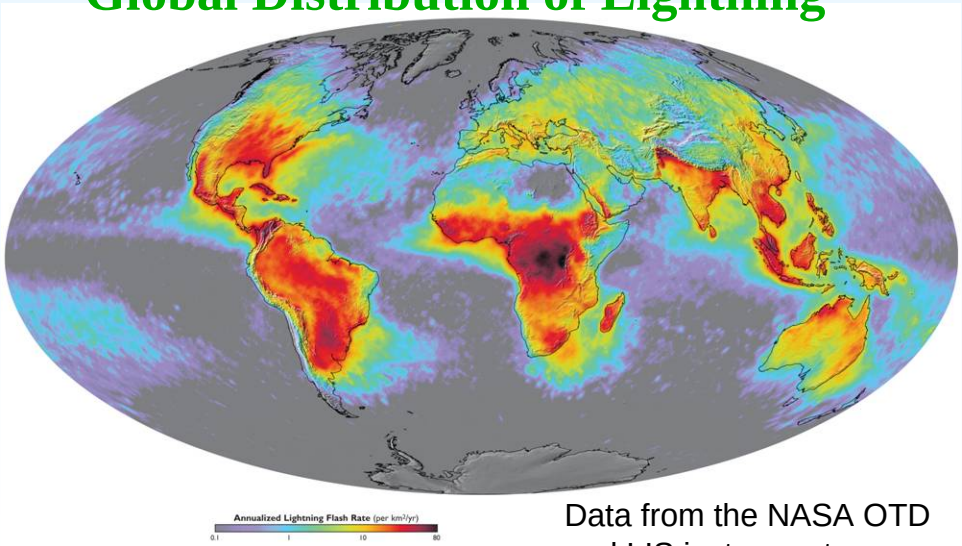
OUTLINE OF TALK

- GLM Overview and Heritage
- GLM Risk Reduction
- GLM Algorithms & Applications
- Summary and Next Steps

Global Distribution of Lightning



Data from the NASA OTD and LIS instruments

GUC V, AMS Annual Meeting, January 20-24, 2008

GLM Overview and Heritage

Observational Requirement	LEVEL	Geo Coverage	Vert. Res	Horiz. Res	Mapping Accuracy	Msmnt Range	Msmnt. Accuracy	Refresh Rate	Data Latency
Lightning Detection	T	CONUS	Sfc to cloud top	10 km	5 km	Real Time	70-90% Detection	Contin-uous	< 1 min
Lightning Detection	T	Hemispheric	Sfc to cloud top	10 km	5 km	Real Time	70-90% Detection	Contin-uous	< 1 min
Lightning Detection	T	Mesoscale	Sfc to cloud top	10 km	5 km	Real Time	70-90% Detection	Contin-uous	< 1min

- **Provide continuous, full-disk lightning measurements for storm warning and nowcasting.**
- **Provide early warning of tornadic activity.**
- **Accumulate a long-term database to track decadal changes of lightning.**

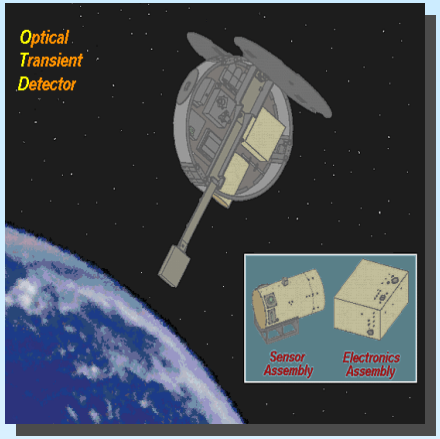
GLM Implementation Status (January 2008)

The GLM is a single channel, near-IR imager/transient detector used to measure total lightning activity over the full-disk as part of a 3-axis stabilized, geostationary weather satellite system

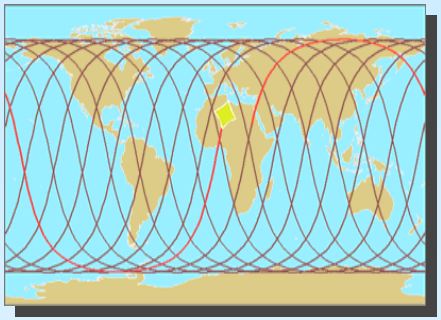
- Heritage: Lightning Mapper Sensor for GOES-M, NASA EOS LIS/OTD

- NASA Lead Role for Instrument
  - » NOAA Funded
  - » RFP Released 26 July 2005
  - » Formulation Studies (3) Completed March 2007
  - » Implementation Phase Contract Valued at $96.7M Awarded to Lockheed Martin Space Systems Company December 2007
    - – 1 Prototype Model
    - – 4 Flight Models

- NOAA Lead Role for Ground System
  - » GOES-R Risk Reduction- Science Team - August 2006
  - » Algorithm Working Group- Lightning Applications Team - June 2007
    - – ATBD, Algorithm Theoretical Basis Document, 2008
    - – Proxy data from the NASA Lightning Imaging Sensor/TRMM and Regional Test Beds (e.g., US Lightning Mapping Arrays- North Alabama, Washington, DC, Oklahoma)

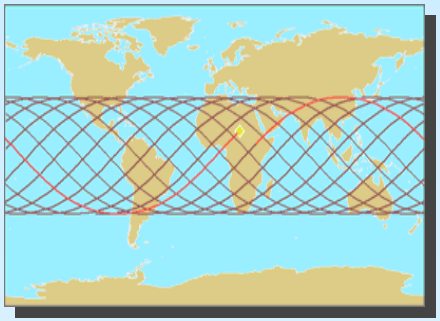


OTD

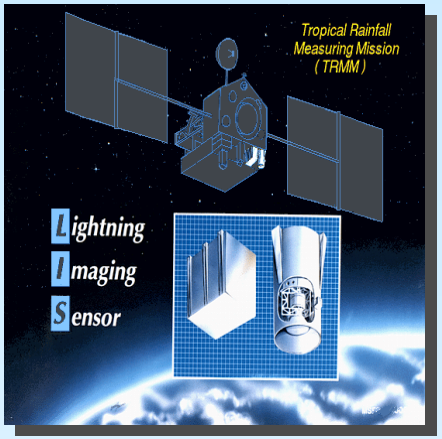


1995-2000

LIS



1997-Present



	OTD	LIS Pre-boost	LIS post-boost	GLM
Inclination	70°	35°	35°	0°
Altitude	735 km	350 km	402 km	42,164 km
FOV (across)	1253 km	583 km	668 km	Full-disk
FOV (diagonal)	1934 km	870 km	1001 km	18,000 km
Pixel FOV (nadir)	7.9 km	3.7 km	4.3 km	8 km
Pixel FOV (corner)	25.9 km	10.3 km	12.0 km	12 km
Observation time	190 s	80 s	92 s	Continuous
Orbital Period	99.5 min	91.5 min	92.56 min	1436 min

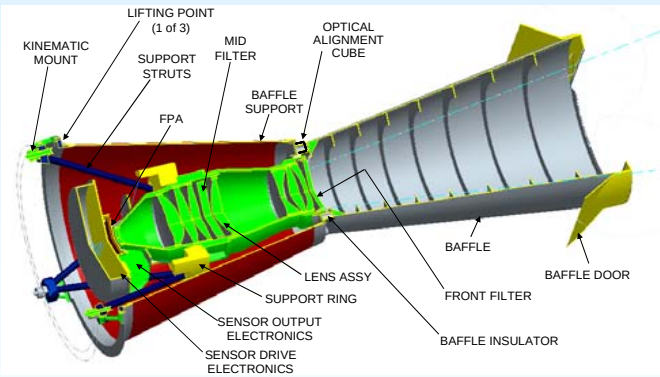
TRMM boost completed August 22, 2001

Integrated System Performance Exceeds Requirements

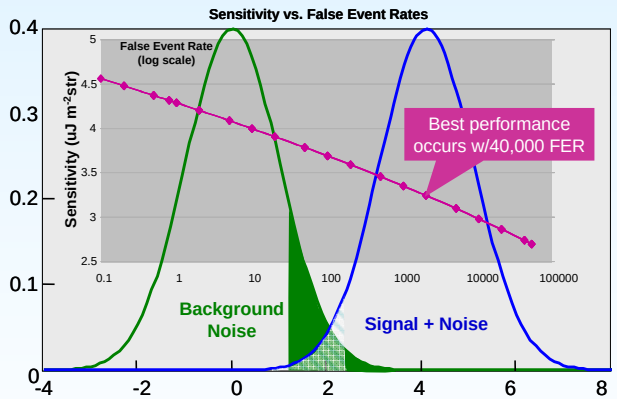
GOES-R GLM Mission Objectives

Provide continuous **Full-Disk** lightning measurements	Provide longer warnings of tornadic activity			Accumulate decadal lightning data
	False Alarm Probability <5%	Detection Probability >70%	Track lightning flash to storm cell; Calculate optical center over time	

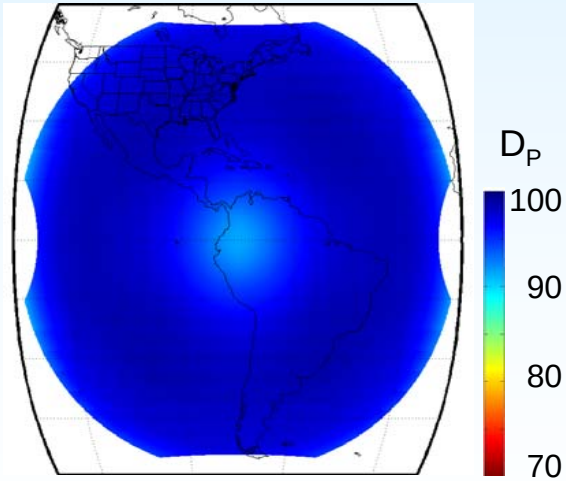
FOV = full-disk [16°]
GSD = 8 km at nadir
1372 x 1300 pixel CCD



False Alarm Probability <5% [<3%]



Detection Probability >70% [>90%]



Black text = requirement
[Blue text] = capability

Robust performance through EOL with high sensitivity and detection probability results in longer warning of tornadic activity

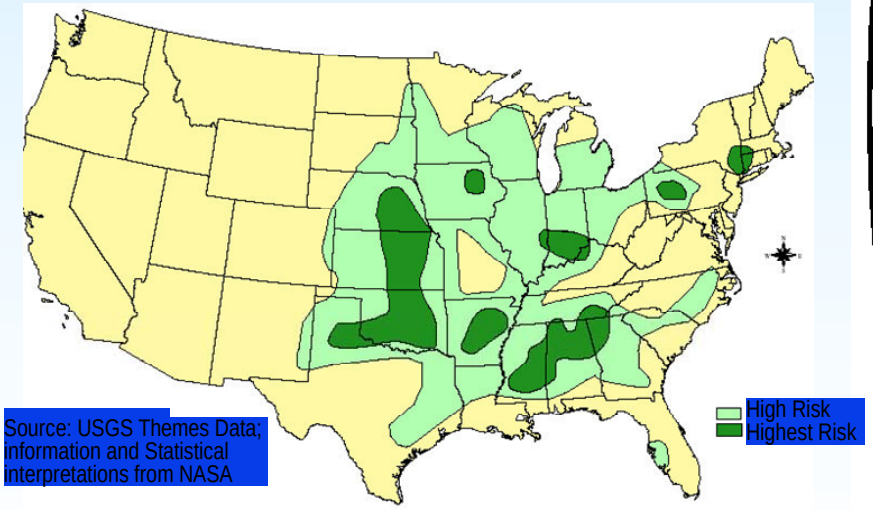
Courtesy LMATC

Predict Good Performance Margins, Especially in Areas With Severe Weather

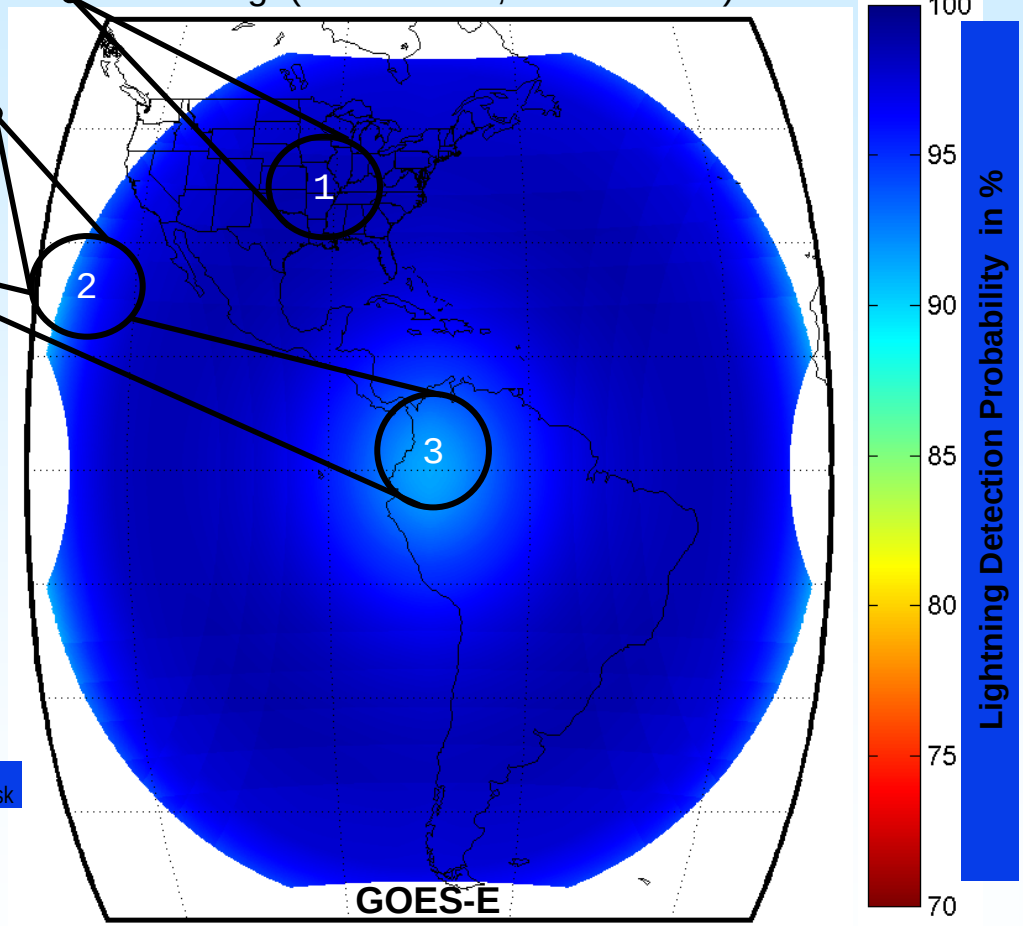
Case 1 [Capability]: **Tornado alley** (5.5°)
Ab = 8 km × 8.5 km [6.8E7 km²]

Case 2 [Baseline]: Edge of FOV (8°)
Ab = 12 km × 8 km [9.6E7 km²]

Case 3 [Baseline]: Nadir (0°)
Ab = 8 km × 8 km [6.4E7 km²]



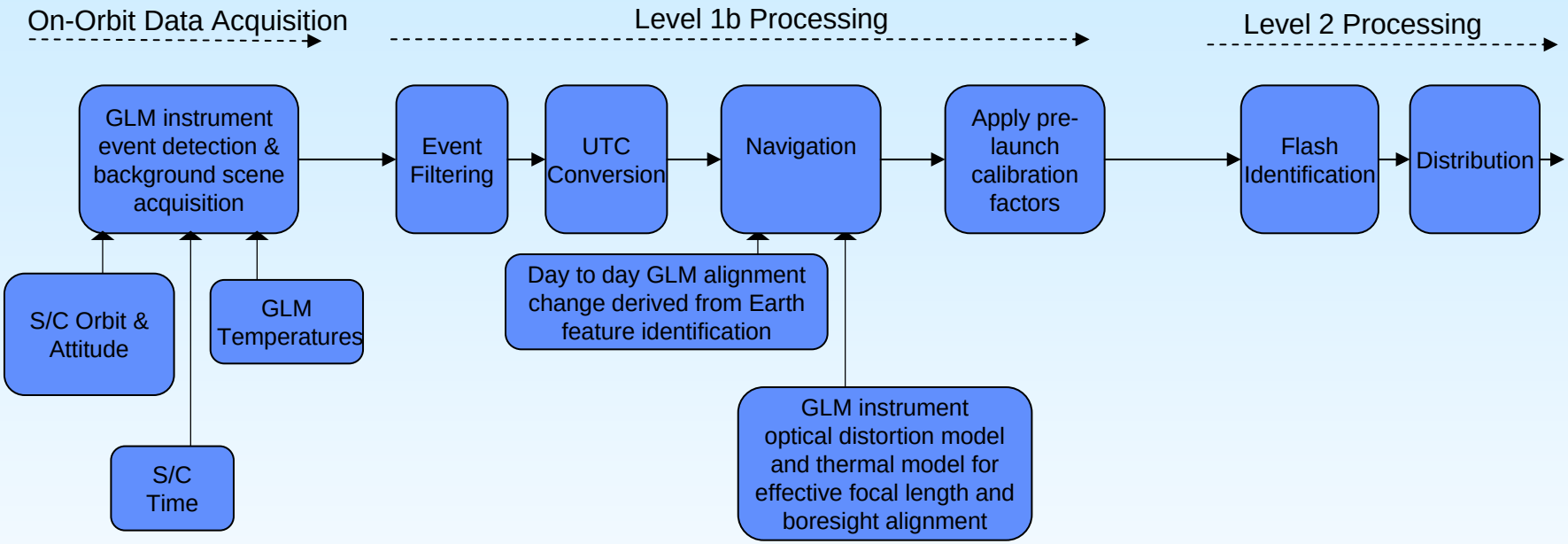
Predicted Detection Probability
24-hr avg. (Min = 88.17; Max = 98.98)



Lockheed Martin's GLM provides detection performance margin in worst-case, daylight conditions and over full-disk, critical geographical areas (Tornado Alley)

Courtesy LMATC

Ground Processing Data Flow



Courtesy LMATC

Ground Processing Algorithms: Process Raw Data to L1B Events

On-Orbit Data Acquisition

1. Background scene tracking & removal
2. Thresholding
3. Event detection

- Background scene acquired
- Background tracking algorithm updates background
  - Response time constant fast enough to track changes caused by S/C motion component
  - Background subtracted from signal pixel by pixel
- Thresholding (events exceeding background are transmitted to ground)
  - Amplitude algorithm processes only larger events
  - Reduces # of processed events so data is compatible with telemetry bandwidth
- Event detected

Level 1/1b Processing

Filter false events

2nd Level Threshold Algorithm (1)

- For cases when there are high event rates – used for rapid removal of false events
- Look-up table

Radiation Algorithm (2)

- Removes false events produced by high energy particle collisions

Shot-noise (coherency) Algorithm (3)

- Removes false events produced by noise (S/C, etc)

Contrast Algorithm (4)

- Removes false events produced by S/C motion

Geolocation

Solar glint Algorithm (5)

- Removes false events produced by solar glint
- Performed after geolocation to minimize processing (only regions within potential glint regions)

Time-tag UTC Conversion

Apply pre-launch calibration factors Convert to radiances

Note: Event to group to flash conversion is processed at Level 2

Layered approach to false event removal results in high system performance

Courtesy LMATC

GLM Risk Reduction

- **Analysis of proxy data from TRMM LIS and VHF Lightning Mapping Arrays**
- **Test beds to collect comprehensive data on storms to advance the science**
- **Forecaster assessments of total lightning data in the Warning Decision-Making Process**

Algorithm Development Strategy

Candidate Algorithms

Testing and Validation

- *Proxy and Simulated Data*
- *Algorithm Selection*
- *Demonstrating Algorithm Performance*

Candidate Algorithms

- **Clustering Algorithm**
  - » Description: takes events and creates groups and flashes
    - – Pros: TRMM LIS and OTD heritage
    - – Cons: non yet extended/optimal for GEO
- **Cell Tracking Algorithm**
    - – Pros: LISDAD and RDT heritage, SCIT has limitations
    - – Cons: technically challenging, needs AWIPS implementation for optimal utility
- **Flash Trending "Jump" Algorithm**
  - » Description: trends flash rates with time for individual storms
    - – Pros: Prototype in development and promising – increase lead time
    - – Cons: Requires additional research, needs AWIPS implementation for optimal utility
- **Other Application Team Uses of GLM**
  - » **Hydology**-Precipitation, **AQ**-NOx/Ozone, **Clouds**-Cloud Type/TRW, Hurricane Intensification, **Aviation**-Turbulence, Convective Initiation, Volcanoes

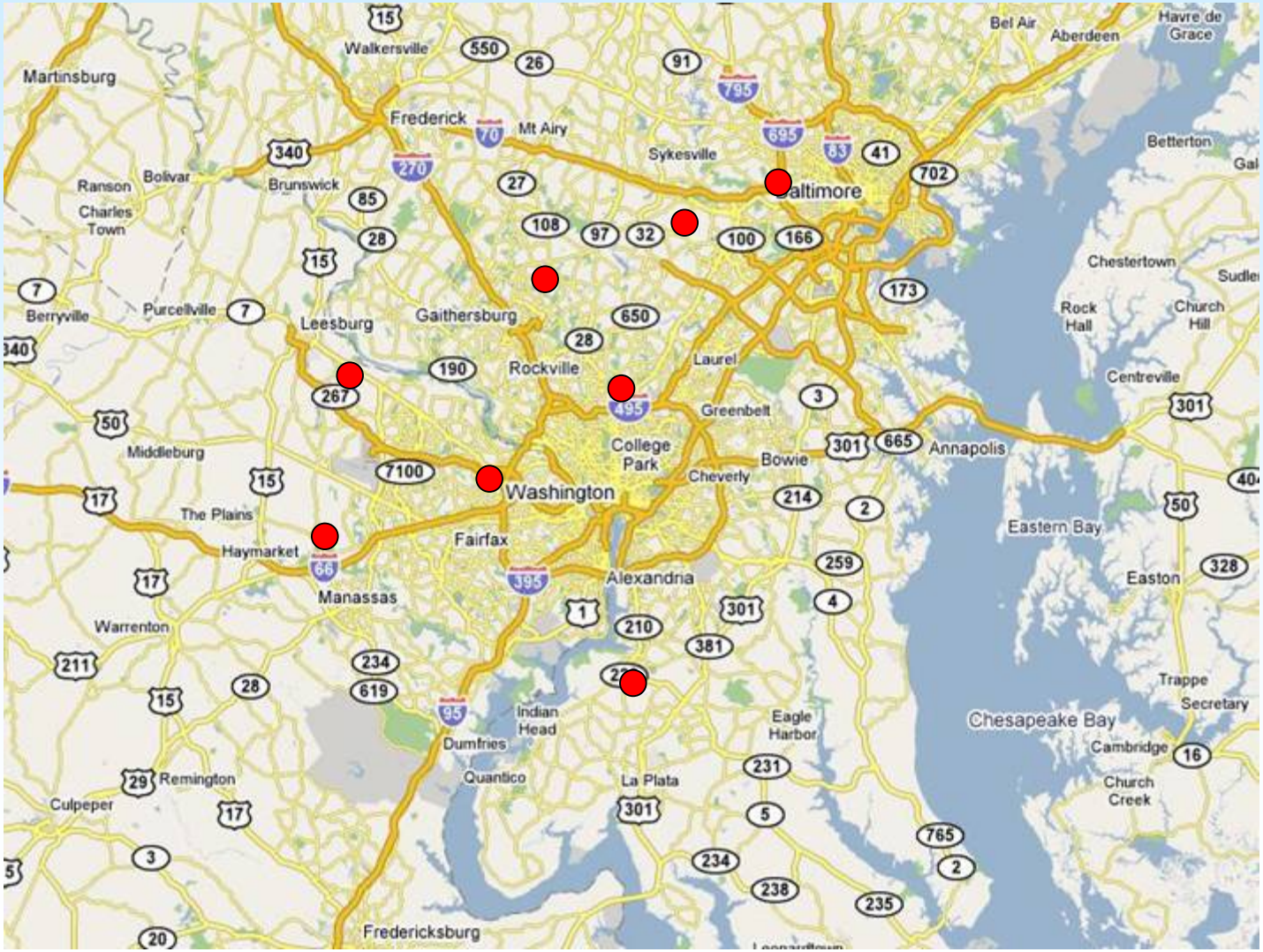
LISDAD- Lightning Information System Data Acquisition and Display (NASA/MIT LL)
RDT- Rapidly Developing Thunderstorm (EUMETSAT SAF/MeteoFrance)

Methodology

- GLM Proxy Data
  - » Inter-compare LMA channel w/ LIS optical to determine how best to use LMA data as proxy to GLM data.
  - » Applications of LMA data (such as in lightning jump algorithm) will extend to GLM using the proxy data.
  - » Re-sampling of LIS data will also serve as an alternate GLM proxy.
- Exploratory Research (see supplementary charts for items below):
  - » WRF model simulations
  - » Interconnections (Ice-precipitation, updrafts, flash rate)
  - » Flash type discrimination
- Clustering/Filtering
  - » Remove non-lightning events
  - » Approach needs to be consistent/coordinated with GLM instrument contractor responsible for L1B algorithms
  - » Lightning products- events, groups, flashes

Washington, DC Lightning Mapping Array

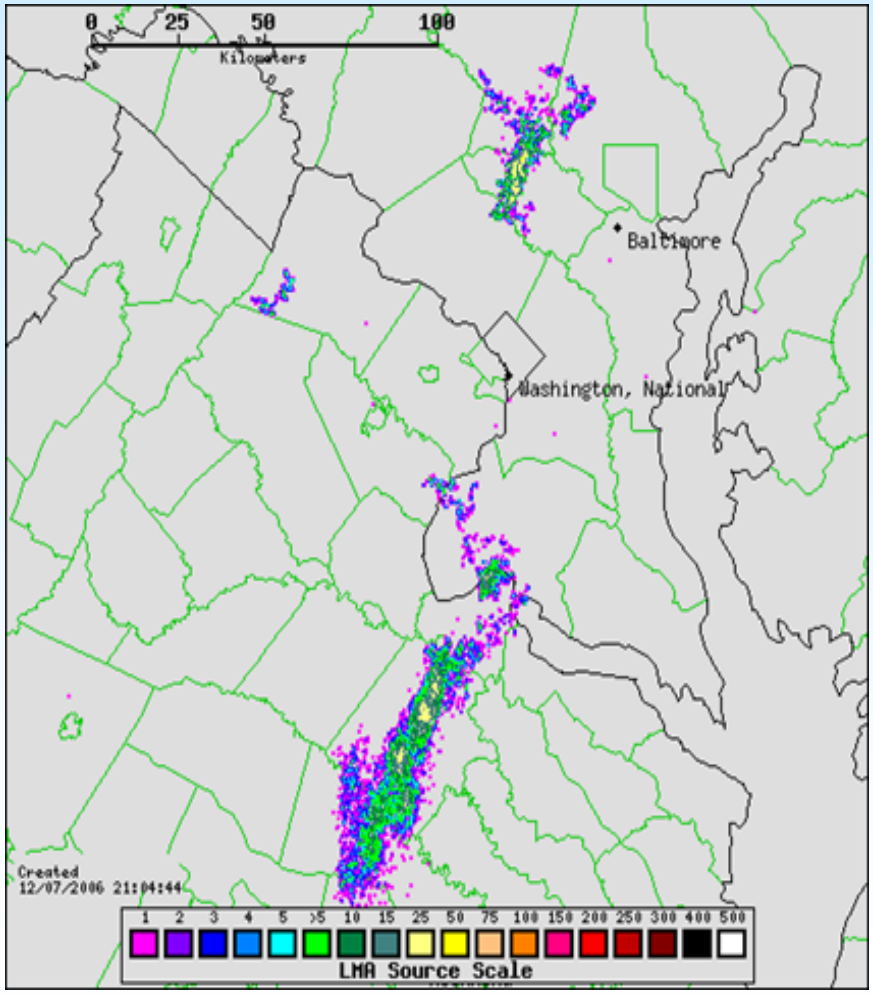
(in progress- 8 stations as of Septembber 2007)



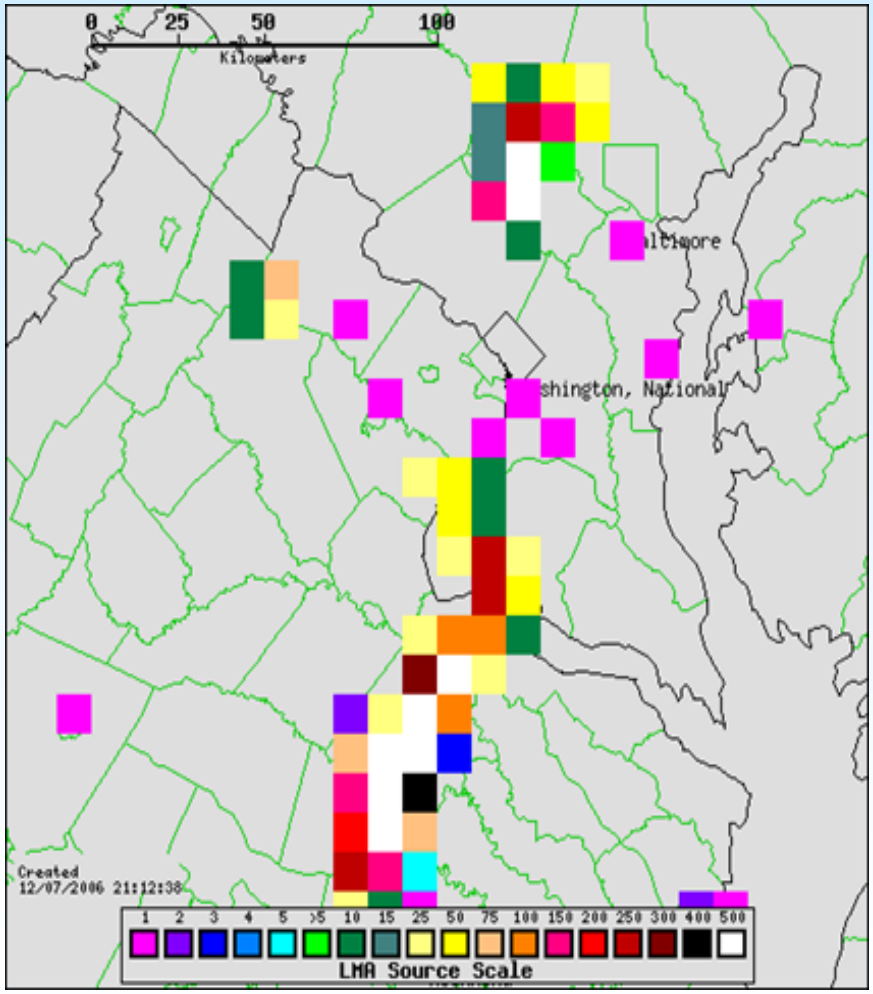
Channel 10, 192-198 MHz (upper VHF), 8-10 stations

DC Regional Storms November 16, 2006

Resampled 5-min source density at 1 km and 10 km



LMA 1 km resolution



LMA 10 km resolution

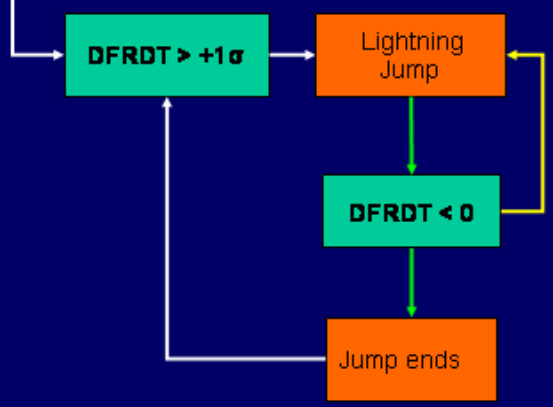
LJA: Lightning Jump Algorithm Identifies Growth and Decay

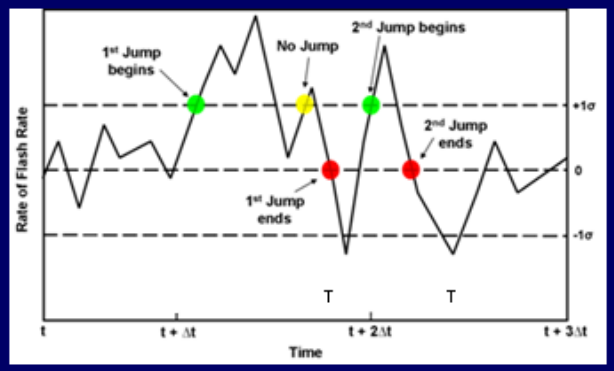
Lightning use in nowcasting severe storms

Strawman "Lightning Jump" Algorithm (Gatlin and Goodman, 2006)

Use of VHF Lightning Mapping Array data (LMA source data currently ingested by AWIPS; SPoRT, NOAA HWT and GOES-R Global Lightning Mapper research)

1. $\frac{d}{dt}(flash\,rate)$ = DFRDT
2. $\sigma(DFRDT)$





- Physical basis: Updraft relationship to electrification
- Initial jump algorithm framework based on 20 severe multi/super cell cases
  - Promising results- POD 1, CSI .513, FAR .482
- Mean and standard deviation thresholds based on pre *and* post-event flash rate means.
- Continue *physically-based* extension/refinement and improvement of algorithm (i.e., FAR, CSI) for broad range of severe storms

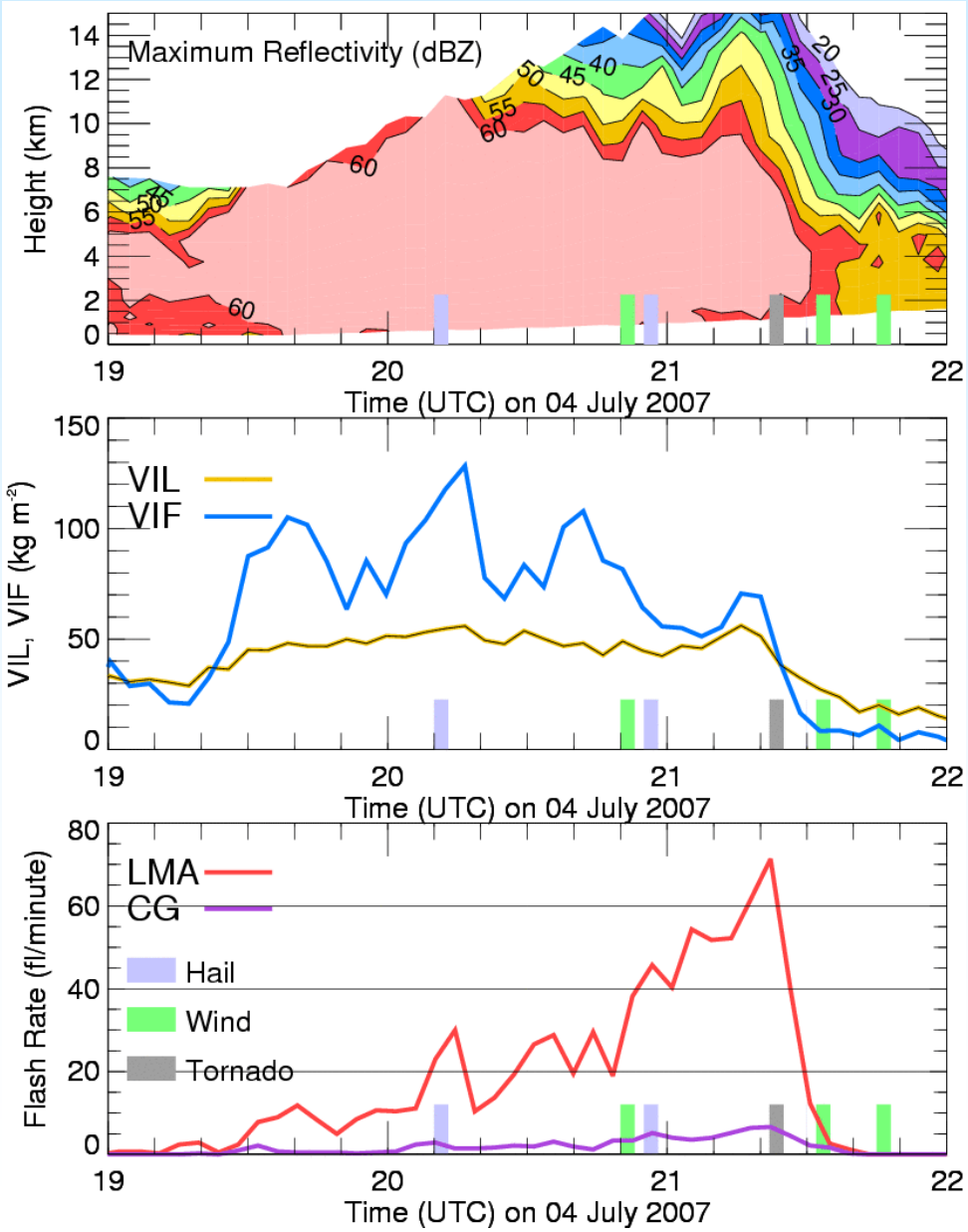
"Jump" Precedes tornado by 18-28 min, avg 17 min

POD- 0.818 FAR- 0.419 CSI- 0.514

P. Gatlin, April 2007, M.S. Thesis "SEVERE WEATHER PRECURSORS IN THE LIGHTNING ACTIVITY OF TENNESSEE VALLEY THUNDERSTORMS"

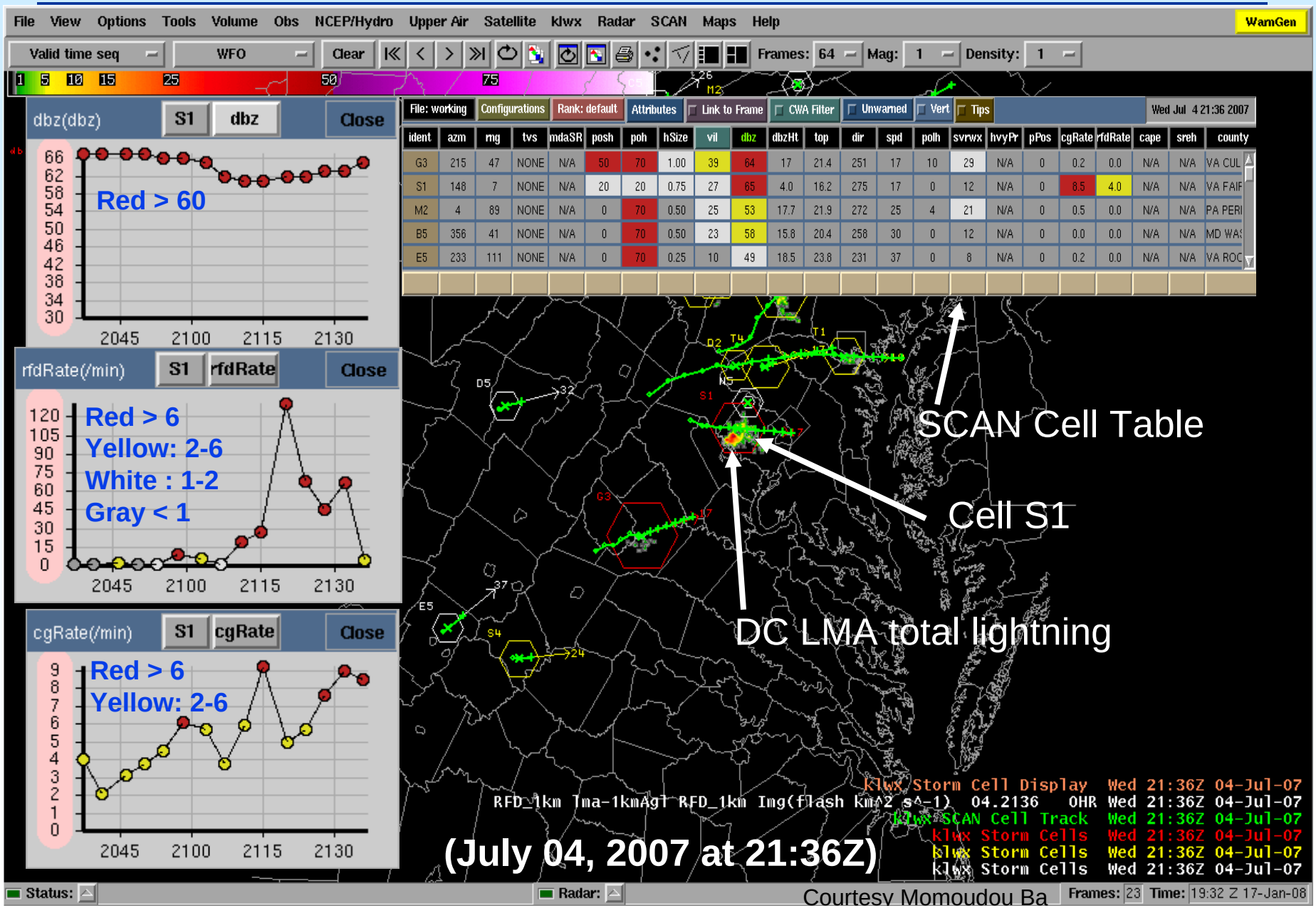
Lightning Jump Algorithm:
Experimental Trending Implementation in AWIPS/SCAN

DCLMA
July 4, 2007



Courtesy Dennis Buechler

Lightning Jump Algorithm:
Experimental Trending Implementation in AWIPS/SCAN



Courtesy Momoudou Ba

Mapping storm initiation, growth, decay

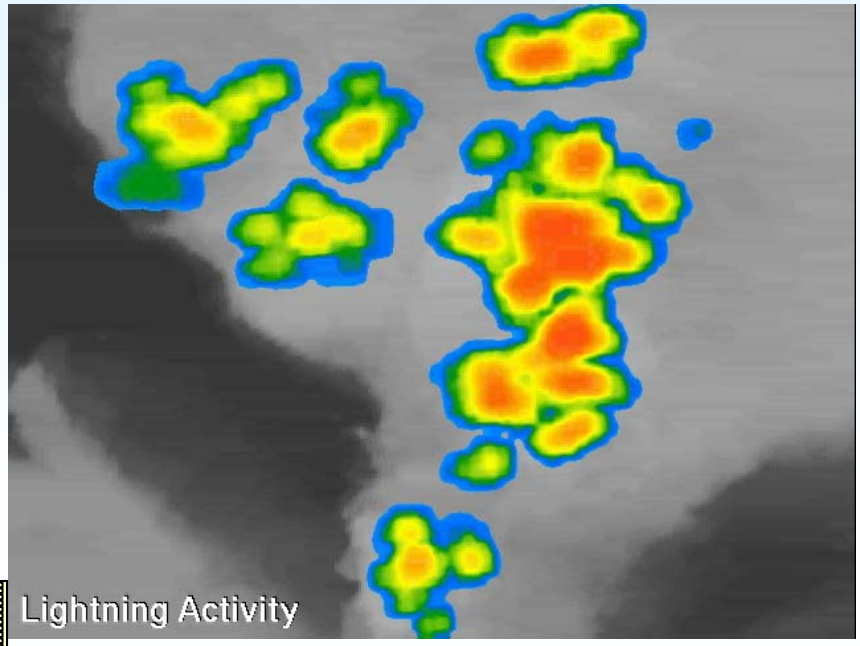
TRMM LIS-Lightning: May 1999 Stroud, OK Tornado

- TRMM provides us a huge database of paired lightning, radar, IR and passive microwave observations (training, validation)

- Over entire tropics & subtropics (generalization)

- Total lightning increases as storm intensifies – can increase lead time for warning of severe and tornadic storms

GOES-R GLM Perspective

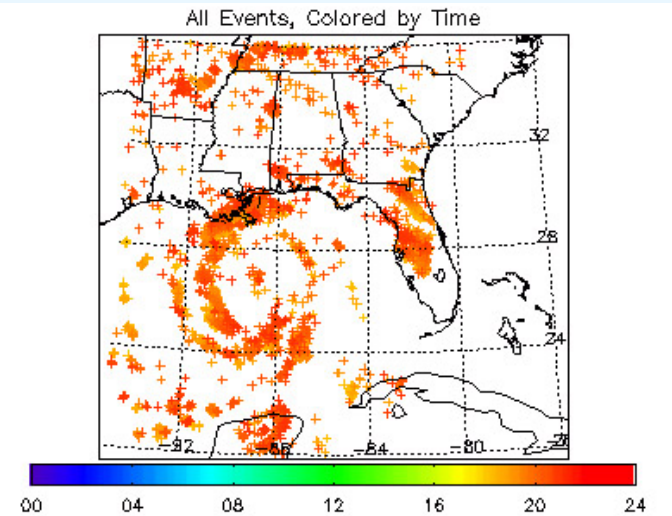


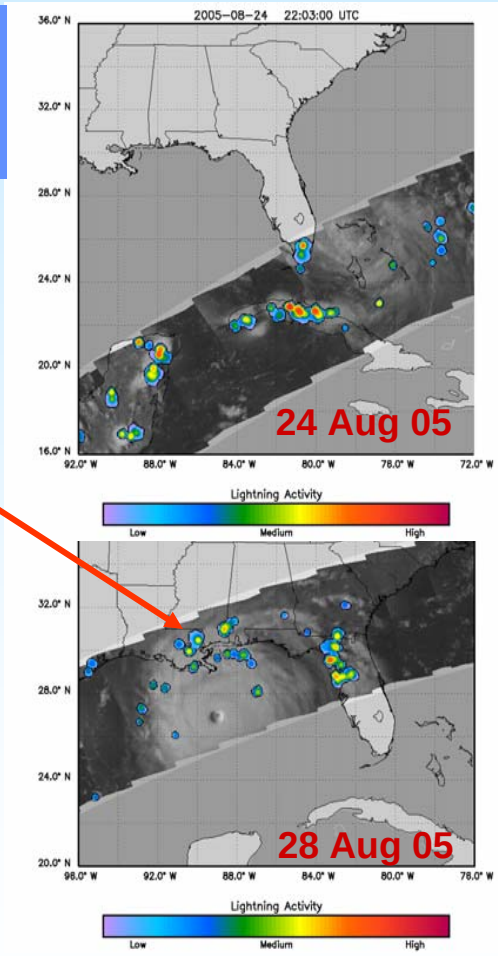
1-min total lightning activity

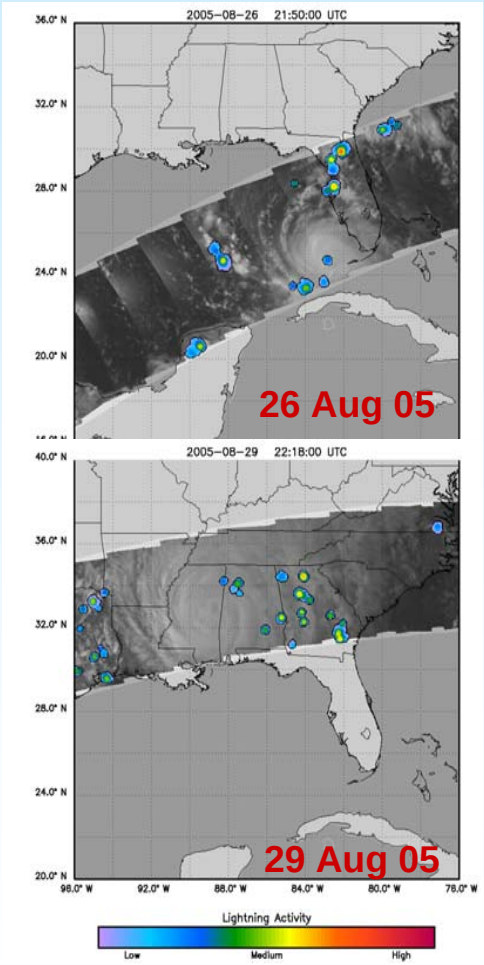
Hurricane Katrina: Lightning Imaging Sensor (LIS)

How does lightning activity vary as TC/Hurricane undergoes intensity change? Is there a useful predictor?

<u>LIS Background Images</u>
read out once per min
4 km ifov @ 777.4 nm
Orbit swath 600 km





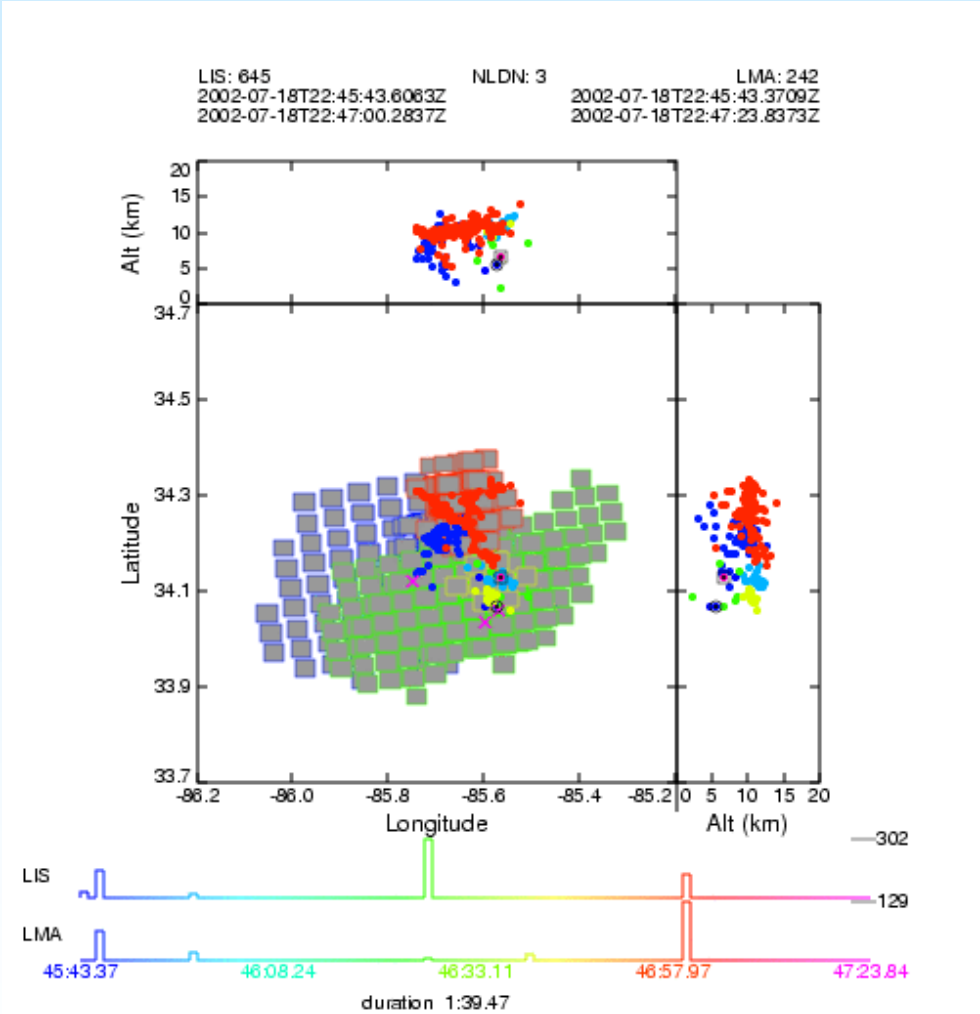


Los Alamos Sferics Array, August 28, 2005, Shao et al., EOS Trans., 86

Testing and Validation
Demonstrating Algorithm Performance…

- Truth data
  - » Ground-based lightning networks, in-situ
  - » Ancillary data
  - » Field Campaigns
  - » Hazardous Weather Testbed- Huntsville, AL and Norman, OK
- Algorithm Test plan
  - » Use proxy/simulated data cases
  - » Perform verification using truth data above in conjunction with proxy/simulated data cases to perform verification
- Error Estimation/Accuracy
  - » Validate against “heritage” ground truth sources above
  - » Metrics: Root Mean Square Error and Bias; POD, FAR, CSI for warning lead time
- Latency
  - » Evaluate run time
  - » Our goal is to process as much data as we can, identify bottlenecks and optimize in order to assess/address latency risks

GLM Proxy Data



Tool developed to start inter-comparing LIS (squares), LMA (dots), and NLDN (Xs) for Proxy Data Development.

Courtesy of Monte Bateman

Testing and Validation
Proxy and Simulated Data…

Proxy Data

- TRMM LIS/OTD- resampled to GLM resolution
- VHF total lightning- remapped to GLM resolution
- SEVERI, MODIS as ABI proxies concurrent with LIS and ground-based lightning data- for merged ABI-GLM products

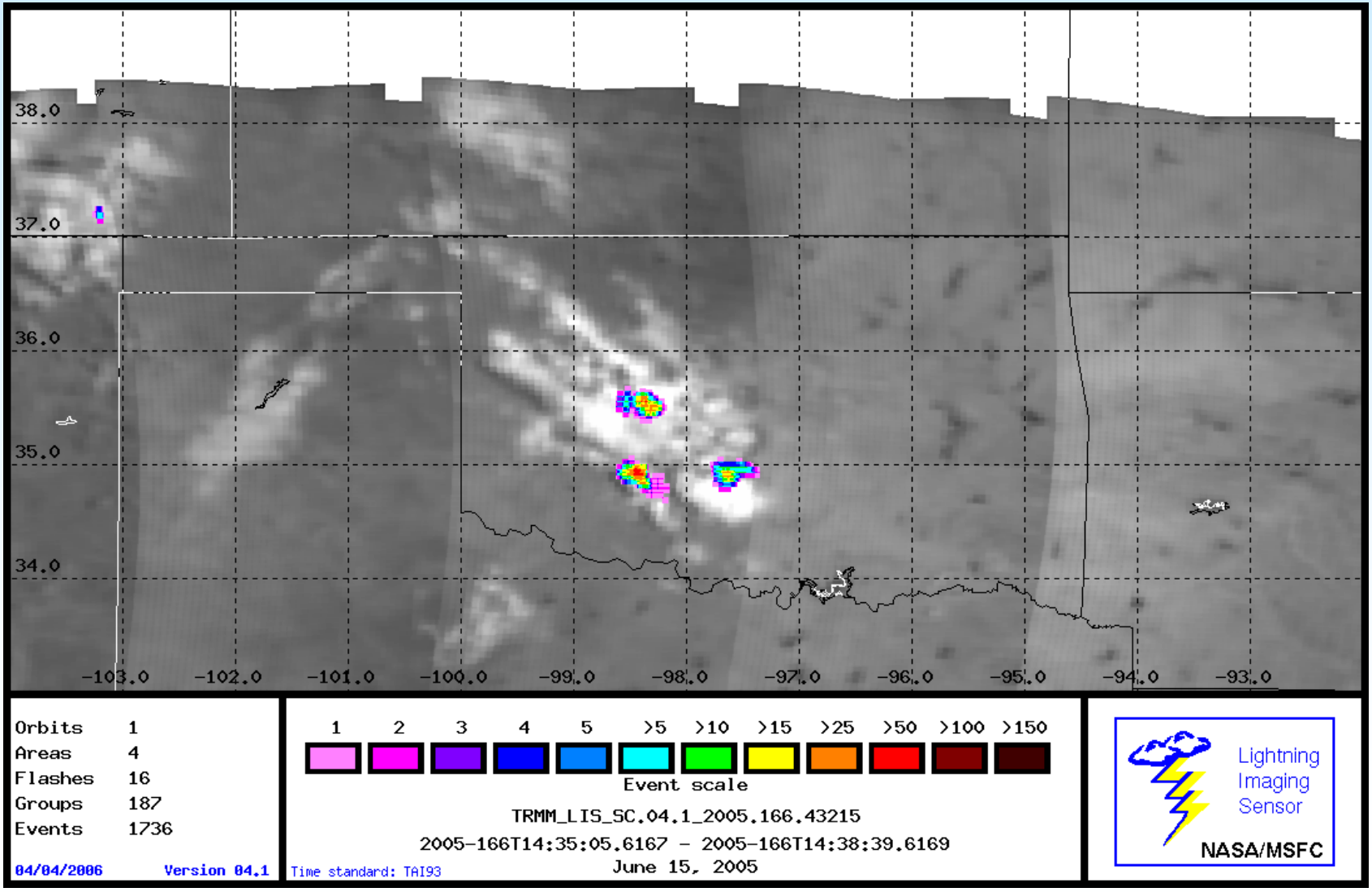
Simulated Data

- WRF, RAMS, cloud resolving models

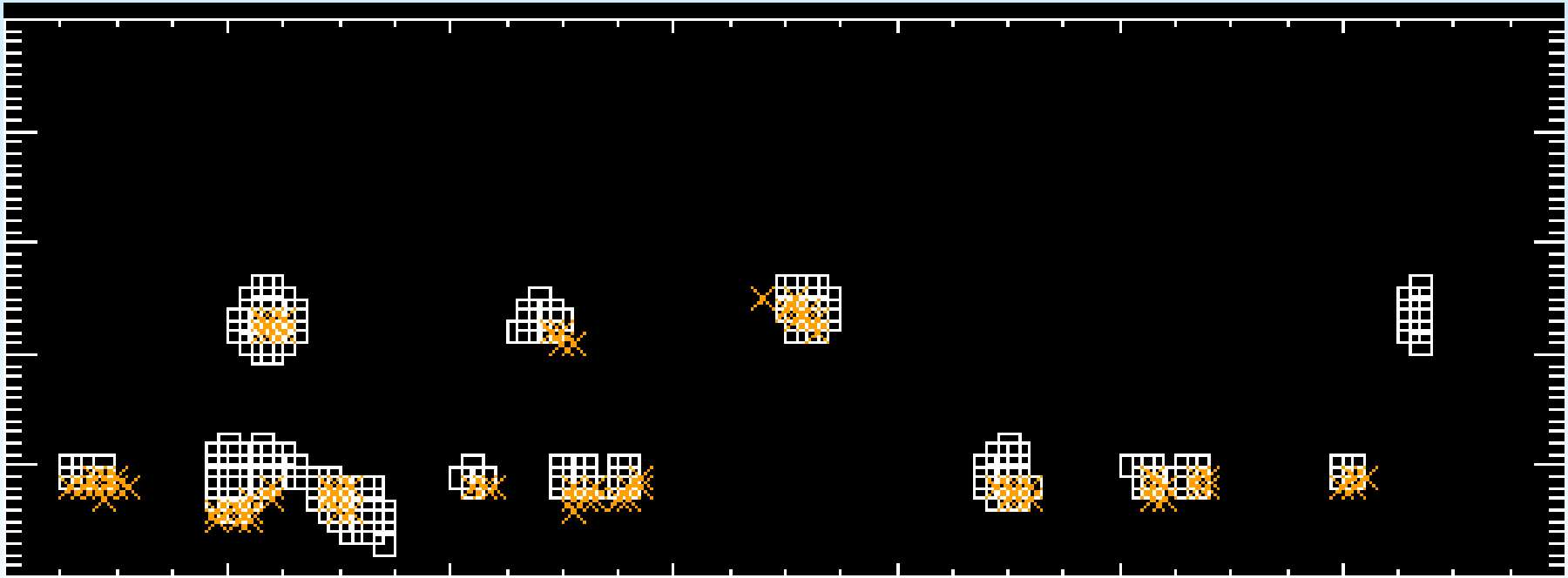
Planned for 2008- concurrent proxy data set - severe storm case in Tennessee Valley (WRF, MODIS, LIS, LMA)

LIS Performance Assessment

6/15/2005 Overpass with LIS Superimposed



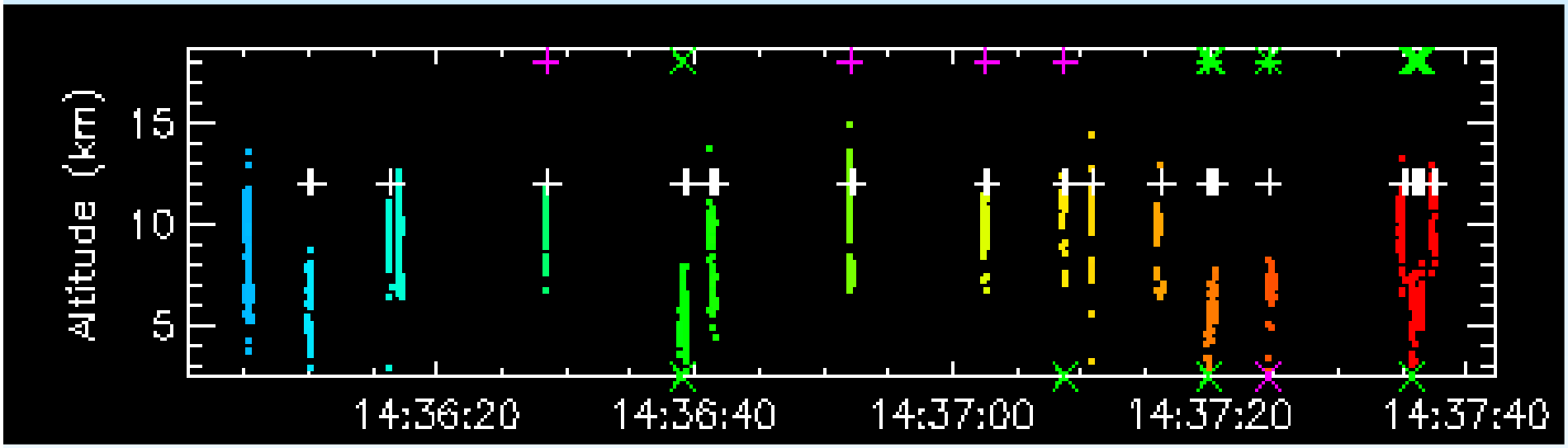
Parallax Correction



- +X forward => data moves from right with time
- LIS footprint squares, calculated LMA = X
- LMA (NSSL) data between 5 km and 14 km altitude

Storm centroiding- need to be mindful of parallax offset when merging GLM with ground-based data, e.g., NLDN, NEXRAD

Coincidence Mapping LIS with other Corresponding Lightning Data



NLDN at 0 km Green X =-CG, Magenta X =+CG

LIS at 12 km White **+**

LMA at Z vs. T position colored by time

LASA at 18 km Green **+** =-IC, Magenta **+** =+IC

LASA Green X =-CG, Magenta X =+CG

Total Lightning Impacts Decision Making

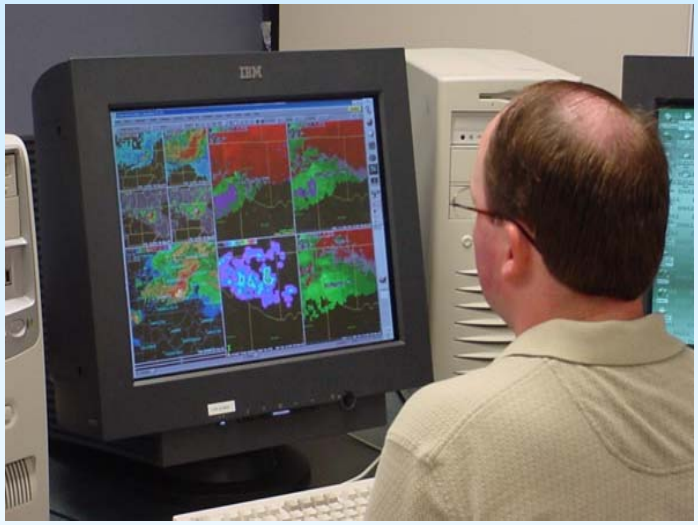
- **Has directly contributed to several correct severe warning decisions at HUN, OHX, and BMX.**

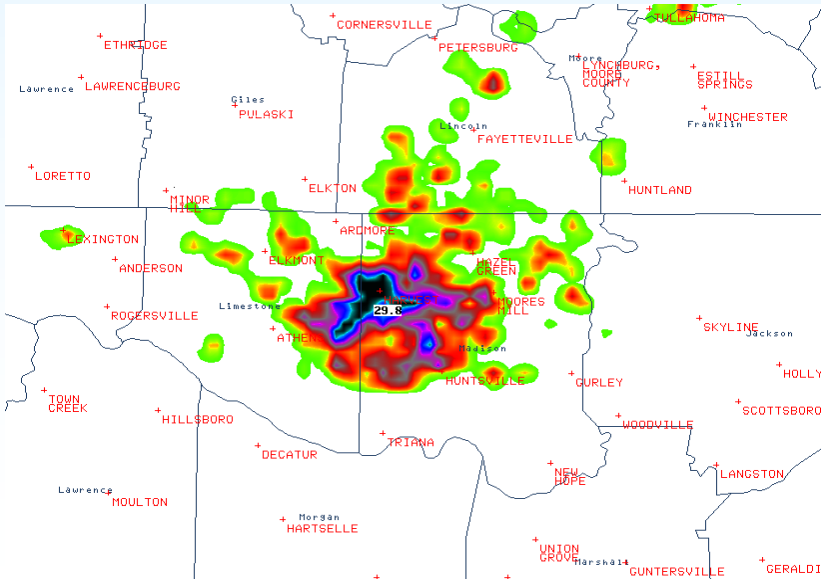
- ***"…the LMA density map gives you a great overall view of where storms with intensifying updrafts are located. So it gives you a good map of where to concentrate attention."***

- ***"I believe the flash density rates were the primary factor in holding off on a warning."***

- **Data archived by WFO**

- **Used in Warning Event Simulator for office training**





Forecast Usage

April 8 HUN Severe Wx - Chris Darden, NWS:

"...As for LMA during the warning process, it certainly did factor into the supercell that strengthened across northern Limestone/Madison Counties and then moved into southern Lincoln County. There was a very nice jump/surge with this one as the rotational couplet tightened. We noticed this in real-time during our "weather watch"..."

Total lightning has directly contributed to several correct severe warning decisions at HUN, OHX and BMX.

Forecast Usage

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE HUNTSVILLE AL
838 PM CDT TUE APR 18 2006

AFTER AN ACTIVE LATE AFTERNOON/EARLY EVENING...SUPERCELL CONVECTION HAS SHIFTED S AND DIMINISHED. GREAT CALL BY THE DAY SHIFT AT BRIEFING TIME...AS THE STATIONARY BOUNDARY THAT LAY ACROSS NE AL LIT UP QUICKLY AROUND 21Z. THE STRONGEST CELLS TRACKED SOUTH ALONG THE BOUNDARY AND DEVELOPED DEEPER ROTATION WITH TIME...AND EXHIBITED STRONG LMA SOURCE DENSITY SIGNALS DURING ROBUST UPDRAFT PERIODS ALSO SHOWN IN THE HIGH VIL/LRM3 REFLECTIVITY FIELDS. LOW LEVEL LAPSE RATES (0-2KM) WERE QUITE STEEP BASED UPON THE KBMX SOUNDING AT 00Z. SIG SVR PARAMETER WAS FAIRLY HIGH THIS EVENING ALONG THIS BOUNDARY TOO. EFFECTIVE DEEP LAYER SHEAR WAS UP TO 40-50KT...SO WITHIN THE ZONE FOR SUPERCELLS. LOW LEVEL SHEAR AND LOW LCLS WERE SOMEWHAT LACKING FOR TORNADOGENESIS.

Conclusions

Significance: The GLM offers a new capability to observe all lightning day and night and with near-uniform coverage of the US and adjacent oceans to improve NOAA's ability to issue forecasts and warnings that will save lives.

Summary and Next Steps

- Develop GLM proxy dataset for testing of GLM algorithms (filtering, clustering, cell tracking, lightning jump) under development.
- Transition heritage TRMM/LIS clustering & filtering algorithms to GEO.
- Continue upgrade of LMA networks, the evaluation of LMA data utility, and the improvement of associated training modules at WFOs.
- Develop cloud-resolving WRF model simulations to predict total lightning flash rates as a function of space & time.
- Jump Algorithm test at selected WFOs (Sterling, VA; Huntsville, AL; Norman, OK; Others)
- Continued AWIPS modifications to support algorithm prototyping
- Investigate connections between precipitation processes, updraft strength, and lightning flash rate.
- Investigate the potential for discriminating ground & cloud flashes based on differences in their cloud-top optical characteristics.