

The Geostationary Lightning Mapper (GLM) for the GOES-R Series of Geostationary Satellites



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Douglas Mach, William Koshak**

GOES-R AWG Lightning Detection Team

NOAA Science Week
NWS Training Center
Kansas City, MO
30 April-2 May, 2012



Lightning Team Members

- **Co-Chairs:**
 - Steven Goodman (NOAA/NESDIS)
 - William Koshak (NASA/MSFC-AWG, IV&V)
 - Richard Blakeslee (NASA/MSFC-R3, Val)
- **Application Team:**
 - Douglas Mach (UAH-AWG)
 - Dennis Buechler (UAH-AWG, IV&V)
 - Larry Carey (UAH-R3)
 - Monte Bateman (USRA-AWG, IV&V)
 - Eugene “Bill” McCaul (USRA-R3)
 - Don MacGorman/Alex Fierro (NSSL-R3, JCSDA FFO)
 - Paul Krehbiel (NMTech-AWG, Val)
 - Eric Bruning (TTech-AWG, PG)
 - Rachel Albrecht (CICS/InPE-R3)
 - Scott Rudlosky (NESDIS/STAR-R3, PG)
 - Geoffrey Stano (SPoRT-Training, PG)

Stakeholders- End Users

- **National Weather Service**
- **NESDIS Satellite Analysis Branch (SAB)**
- **Department of Defense (DoD)**
 - Air Force Weather Agency (AFWA)
 - Fleet Numerical Meteorology and Oceanography Center (FNMOC)
 - Joint Typhoon Warning Center (JTWC)
- **NASA**
 - KSC-ETR/Launch Commit Criteria
 - SMD- science (O2R)
- **Federal Aviation Administration (FAA)**
- **USDA- Forest Service**
- **Bureau of Land Management (BLM)**
- **Department of Energy**
- **EPA**
- **NSF-Universities**
- **Private Industry**
- **EUMETSAT (GEO WG)**



Outline

- GLM Instrument
- AWG Lightning Cluster/Filter Algorithm
- GLM Validation
- GLM Applications
 - Concept of Operations - Lightning
- GLM Related Posters
- Summary

Specifications

- Continuously maps all (in-cloud and cloud-to-ground) lightning events
- Provides early indication of storm intensification and severe weather events; tornado warning lead time of 20 minutes or more
- CCD event detector
 - 777.4 nm wavelength
 - 2 ms frame rate
 - 7.7 Mbps downlink rate
- Near uniform spatial resolution
 - 8 km (nadir) – 14 km (edge of FOV)
 - 70-90% flash detection
- Product availability < 20 sec

Current Status

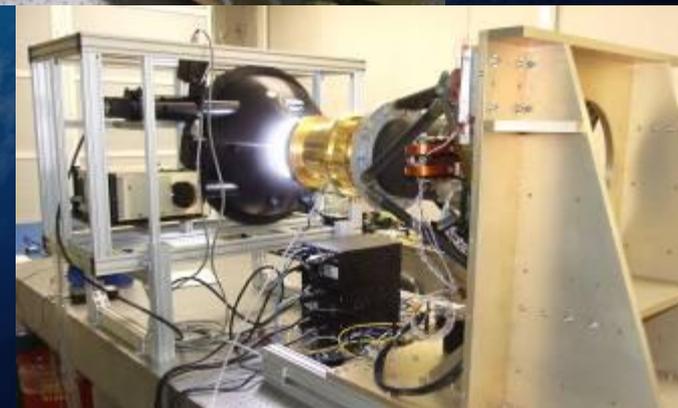
- Flight fabrication is underway
- FM1 delivery summer 2013



Optical Assembly

Metering tube

Sensor Unit
Mechanical
Support Structure



Primary Contractor: Lockheed Martin Advanced
Technology Corp of Palo Alto, CA

GLM Sensor Unit Overview



Baffle Support

Solar Rejection Filter

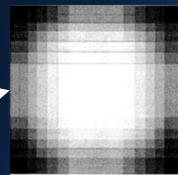
Solar Blocking Filter



Baffle & Door



Lens Housing & Support Structure



Variable Pitch CCD

Narrow Band Filter

Metering Tube

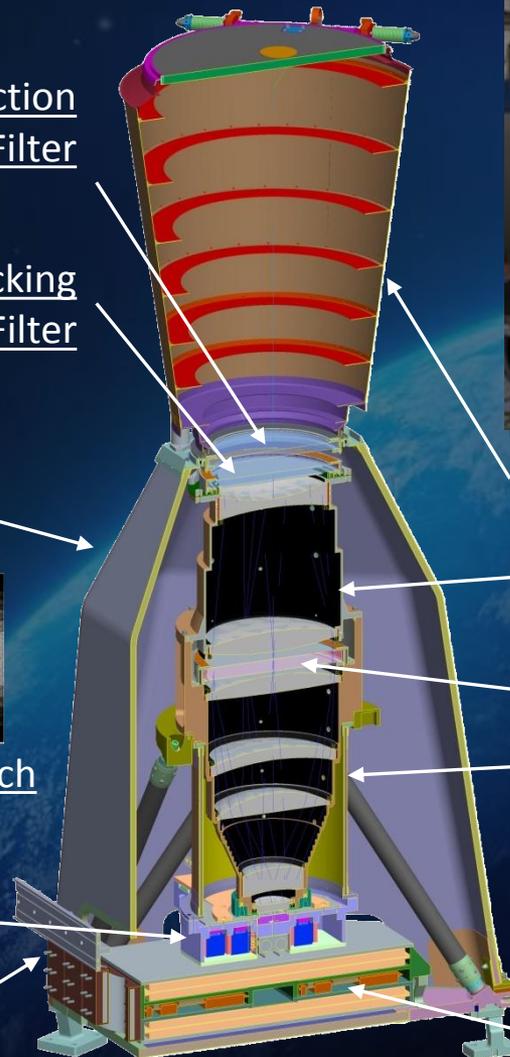


Focal Plane Array Assembly (FPA)



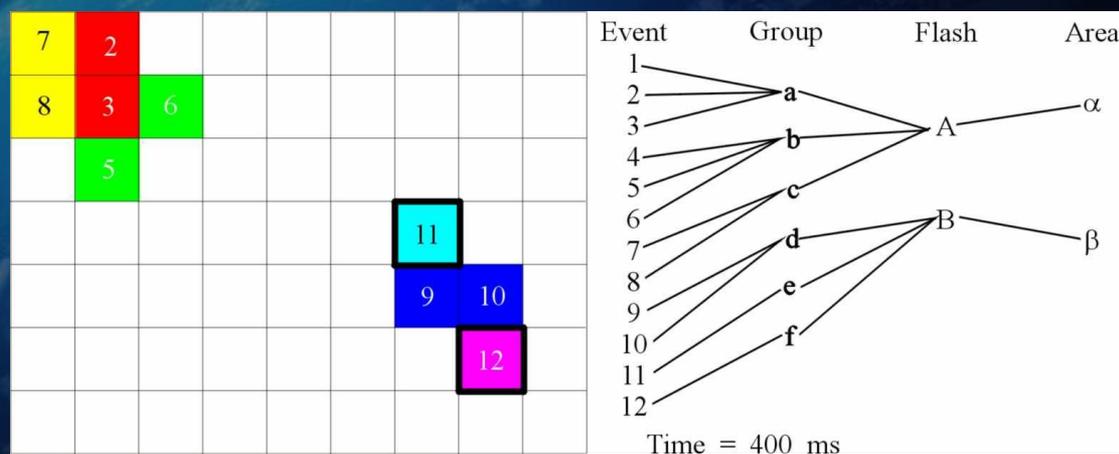
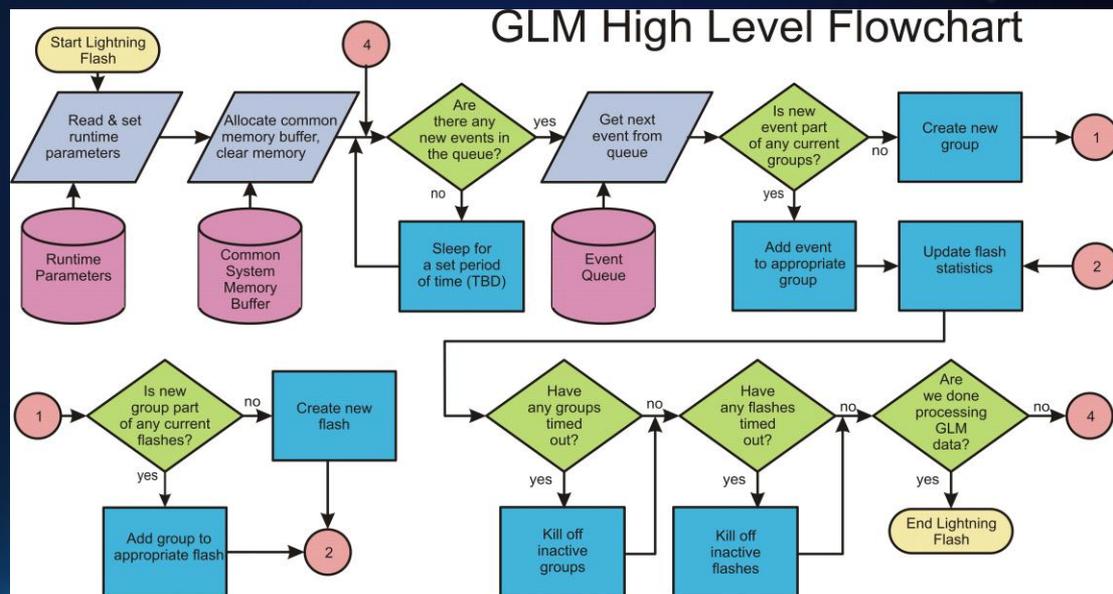
Loop Heat Pipes (FPA) and Thermal Straps (SEB)

Sensor Unit Electronics Box (SEB)



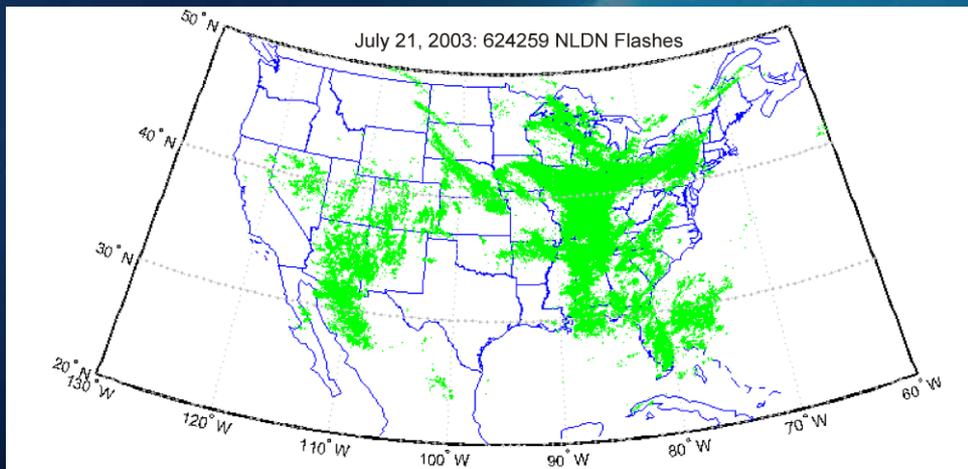
Lightning Cluster/Filter Algorithm (LCFA)

- Algorithm Has Not Been Modified
- Based on Analysis of Over a Decade of Data from LIS/OTD
- Only QA Components Have Changed (evolution of QA data based on L1B code development)
- Harris/AER Implemented LCFA/ATBD... (March 2012)

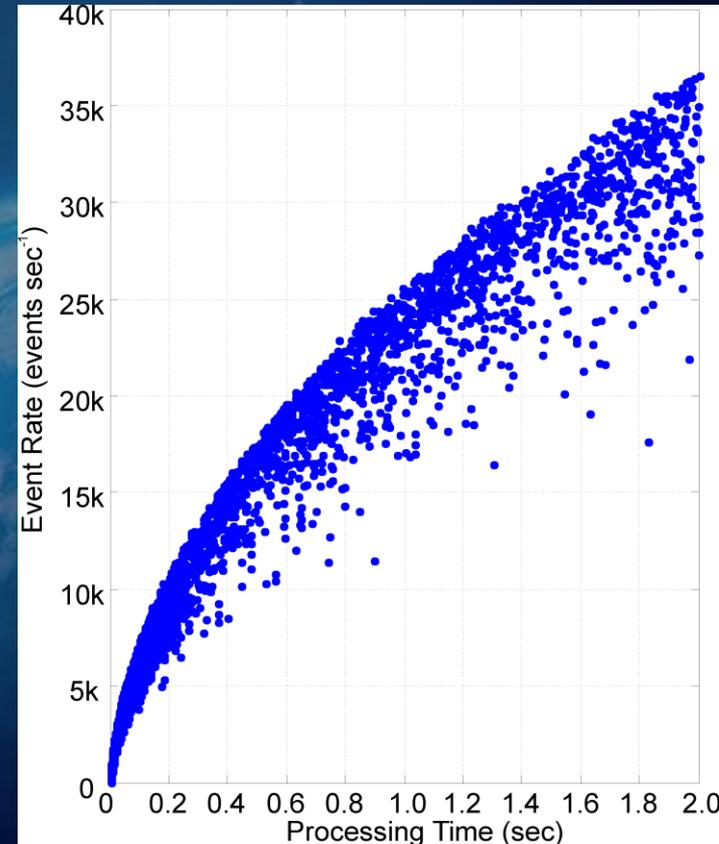


GLM Code Speed Tests

- Tests Indicate Code Can Meet Latency Requirements
 - Proxy data tests on single thread GLM code on target system indicate that the code can process 20,000 to 25,000 events in less than 1 second of computer time
 - Current estimates of maximum GLM data rates are around 40,000 events/sec (mean rates nearer 150 events/sec)
 - We can process a nominal second of GLM event data in less than 1 second of computer time and well less than the 4 second latency requirement



Vaisala NLDN used to scale max expected flash rate



Max Event Rate Test



AWG Lightning Detection Harris/AER Interactions

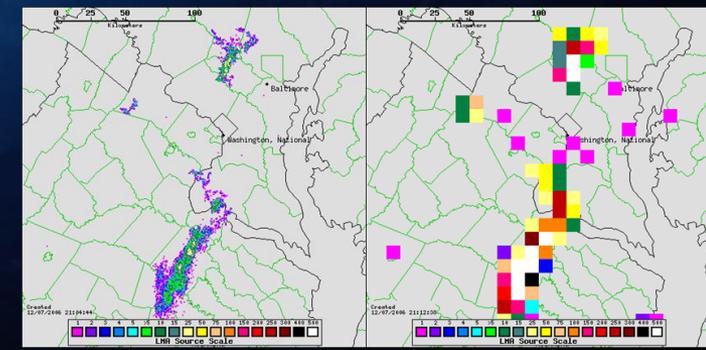
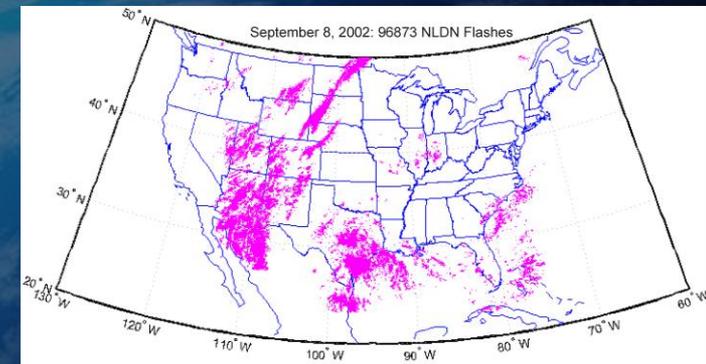
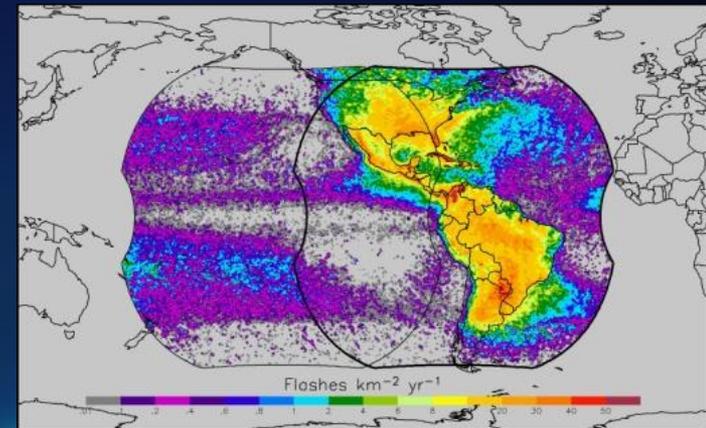
- Series of TIMs (Technical Interchange Meetings)
- Series of Document Interchanges
(Questions/Answers/Clarifications/Resolutions)
- Interactions Allowed Harris/AER to Fully Understand the LCFA and the Expected Inputs and Outputs
- Resulted in Contractor Code Meeting or Exceeding Requirements
 - Specifications: 0.95
 - Achieved 0.99 (or better)

GLM Validation



GLM: Lightning Optical Pulse Detector

- GLM Detects Optical Pulses From CG and IC Flashes Over Nearly the Full GOES-R FOV
- NLDN Detects VLF From Mostly CG Flashes Over Mostly the CONUS & Canada (up to 90% of lightning is IC)
- LMA Detects VHF From CG and IC Flashes Over a Limited Range (at location of network)



Proxy Data/Validation Posters:

Integrated GOES-R GLM/ABI approaches for the detection and forecasting of convectively induced turbulence (CIT) - Carey, Feltz, Bedka, Monette, Wang, Rogers, Scott

GOES-R AWG GLM Val Tool Development - Bateman, Mach, Goodman, Blakeslee, Koshak

Intercomparison of Lightning Location Systems during CHUVA-GLM field campaign and thunderstorm characteristics - Albrecht, Morales, Goodman, Blakeslee, Bailey, Carey, Mach, Hall, Bateman, Rudlosky, Holler, Betz, Mattos, Nag, Said, Lojou, Heckman, Pinto Jr., Naccarato, Saraiva, Saba, Holzworth, Anderson, Collins

Validation Data

- **Ground Truth Datasets:**



- Short-Medium Range Lightning

- LMA (North Alabama (NASA-NOAA), DC (NASA-NOAA), Oklahoma (OU CIMMS-NSSL), West Texas (TTU), NMTECH, Camp Blanding (UF-DARPA), Colorado Front Range (CSU), Houston (TAMU), NASA-KSC and Wallops, Atlanta (GTRI), St. Louis (SLU-Cardinals baseball))

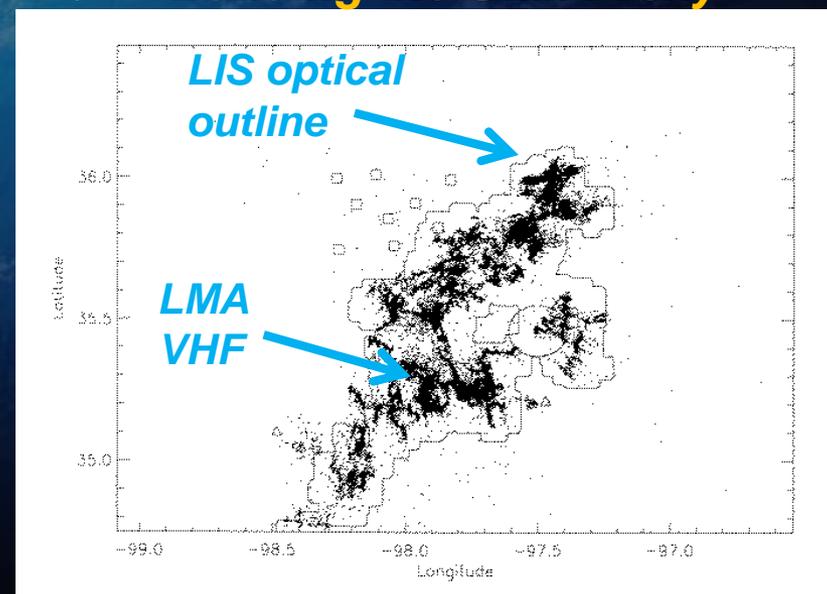
- HAMMA/Delta E Array (North Alabama)

- High Speed Video Cameras
- KSC Field Mills (KSC Florida)
- NLDN (CONUS)

- Long Range Lightning

- GLD360
- WWLLN
- ENTLN

Building the GLM Proxy



Validation Data (cont.)

• Additional Ground-Based Systems for Field Campaigns

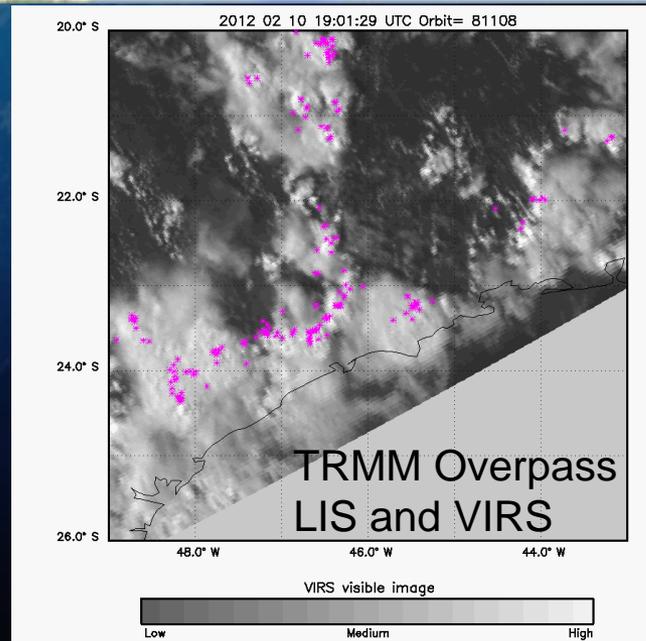
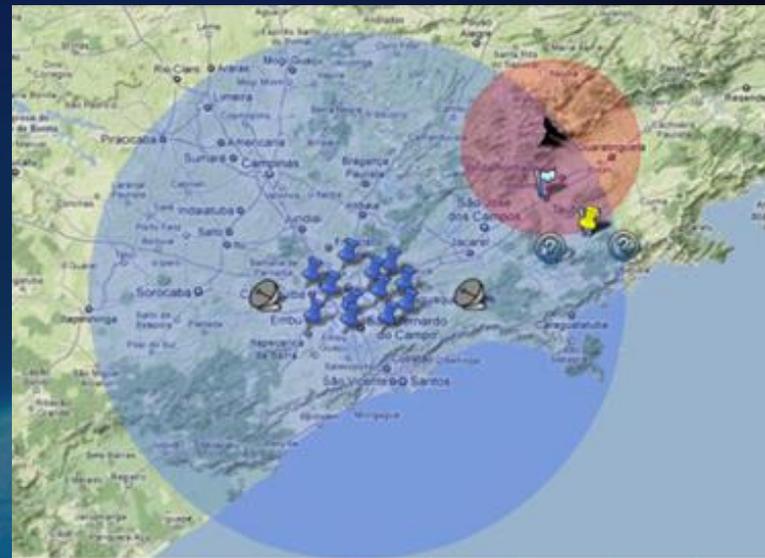
- CHUVA SOS- Sao Jose dos Campos (Nov. 2011-March 2012)
 - SPLMA (Sao Paulo Brazil), ENTLN, RINDAT (CG)
- DC3 (May-June, 2012)
 - FCLMA (Fort Collins Colorado), OKLMA, NALMA
- HyMeX (SOP-1 Sept-Oct 2012)
 - Deployed LMA in March 2012 (Mediterranean region)
 - Bill Rison (VSP, NMTech) to participate in HyMeX SOP-1 (Sep-Oct 2012)
 - GOES-R MOU with HyMeX allows full access to their data and NWP



GLM CHUVA Campaign- Nov 2011- Mar 2012

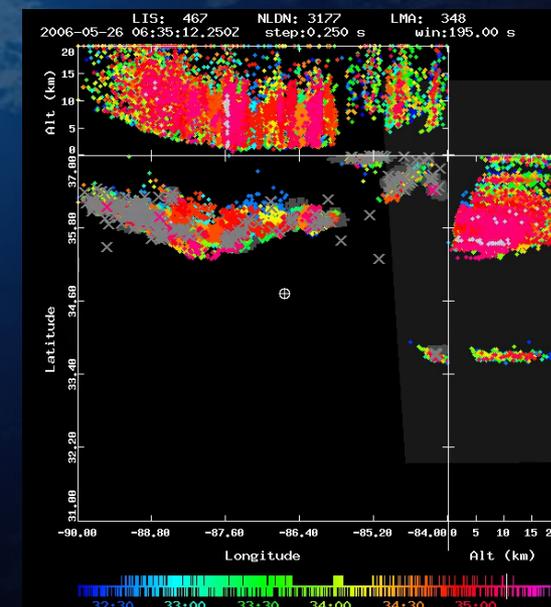
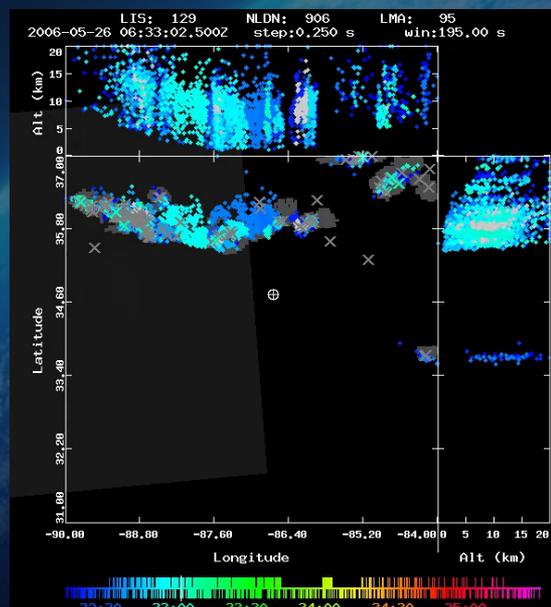
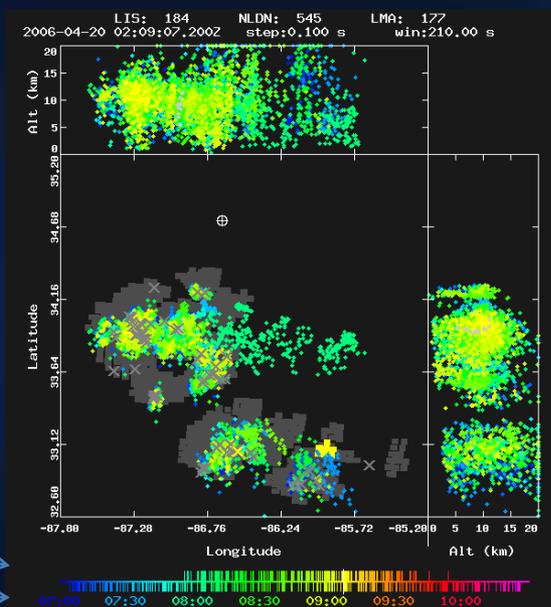
- Excellent Cross-Network Inter-Comparisons and Performance Assessments
- Improved Understanding of
 - Convective Initiation
 - Thunderstorm Physics
 - Nowcasting Applications
- Generation of GLM Proxy Data
- Concurrent SEVIRI and LIS Data
- Better Understanding of Lightning/Storm Interactions

See: **Intercomparison of Lightning Location Systems during CHUVA-GLM field campaign and thunderstorm characteristics** - Albrecht, Morales, Goodman, Blakeslee, Bailey, Carey, Mach, Hall, Bateman, Rudlosky, Holler, Betz, Mattos, Nag, Said, Lojou, Heckman, Pinto Jr., Naccarato, Saraiva, Saba, Holzworth, Anderson, Collins



Validation Tools

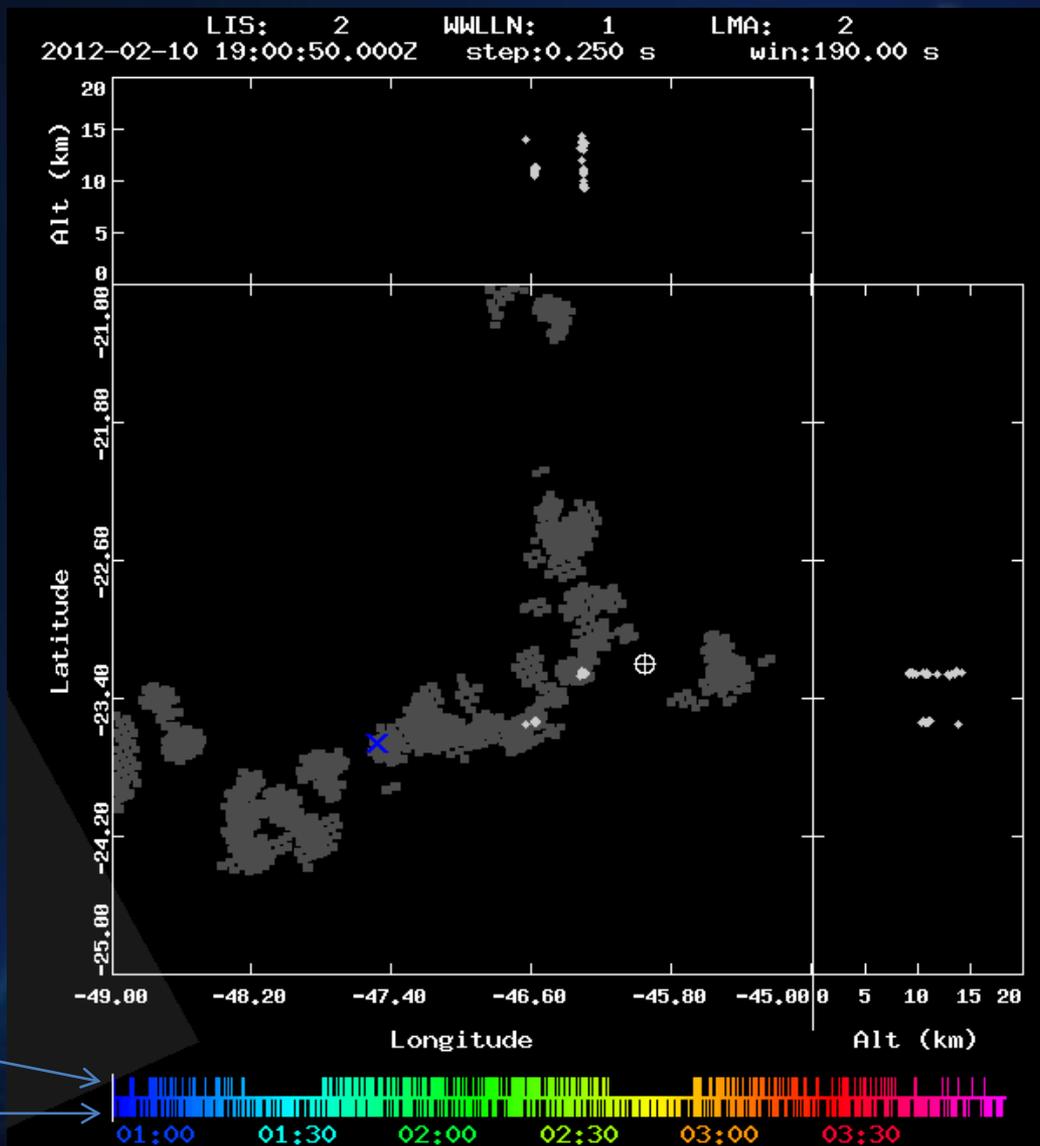
- Best Proxy GLM is LIS
- LIS Data Not Always Available
- Tool Uses LMA as “Seed”
- Output a Statistical Match for LIS/GLM Data
- Tools Developed to Assess LCFA software
- By Comparing LFCA Output with “Seed” Data, Can Test Clustering
- Results Indicate LFCA is Performing Exactly as Should
- Tools Developed to Help Visualize the Many Data Streams Needed to Assess Performance of GLM (cal/val)



See: **GOES-R AWG GLM Val Tool Development** - **Bateman, Mach, Goodman, Blakeslee, Koshak**

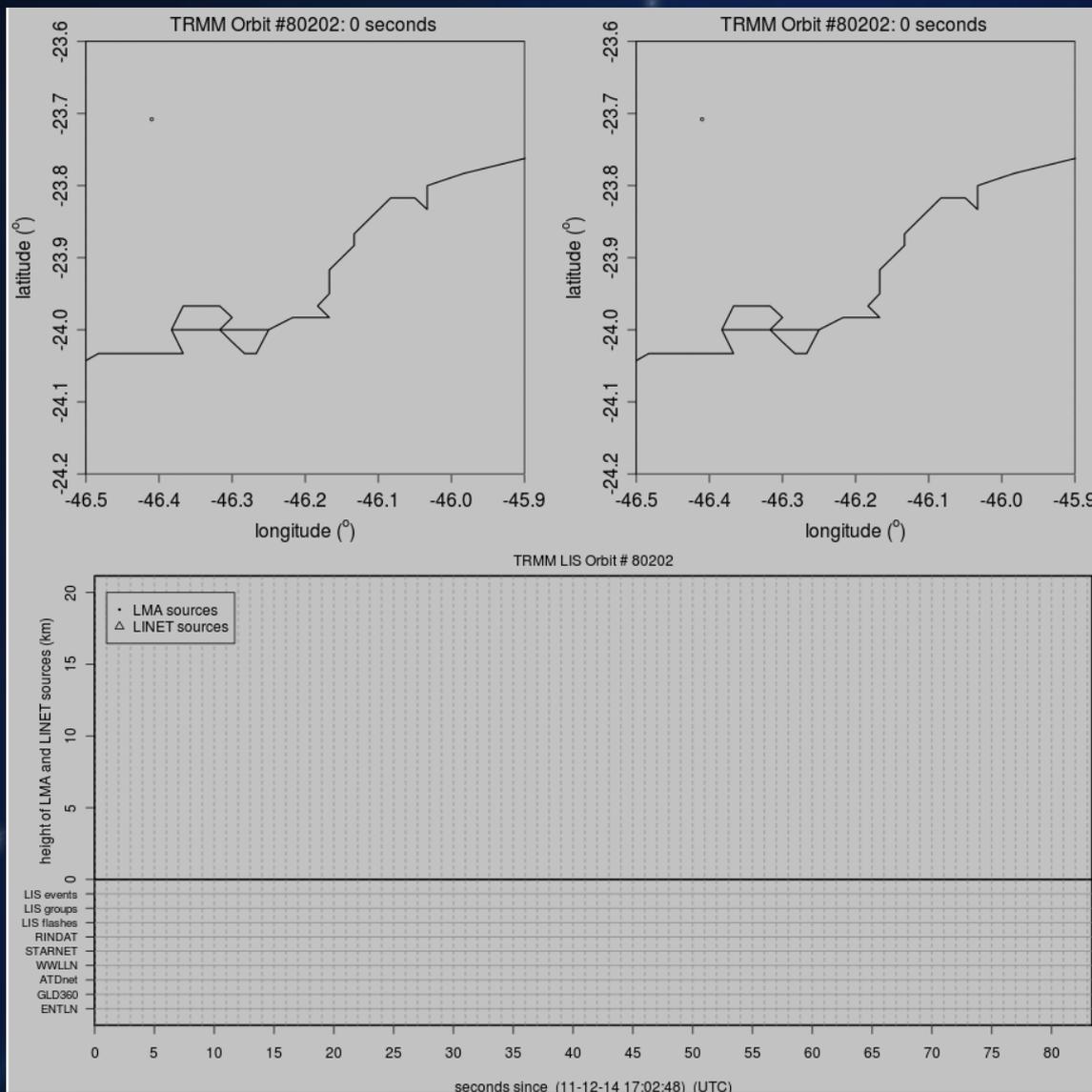


SPLMA, WWLN TRMM/LIS Overpass February 10, 2012 GLM CHUVA Campaign



Courtesy, Monte Bateman

SPLMA, WWLN TRMM/LIS Overpass February 10, 2012 GLM CHUVA Campaign



Validation Data (cont.)

• Airborne GLM Simulator



- Build an airborne detection system that will make high resolution optical measurements as a GLM simulator.
- Deploy on aircraft (e.g., ER2, Global Hawk) to observe cloud-top lightning pulses (target DC3, HS3, other field campaigns).

• Satellite Observations

– LIS

- GLM proxy data development
- Pre-launch validation simulations (including val tool testing)
- Pursue opportunity to a LIS on International Space Station
- TRMM Extended Mission ? (next slide)



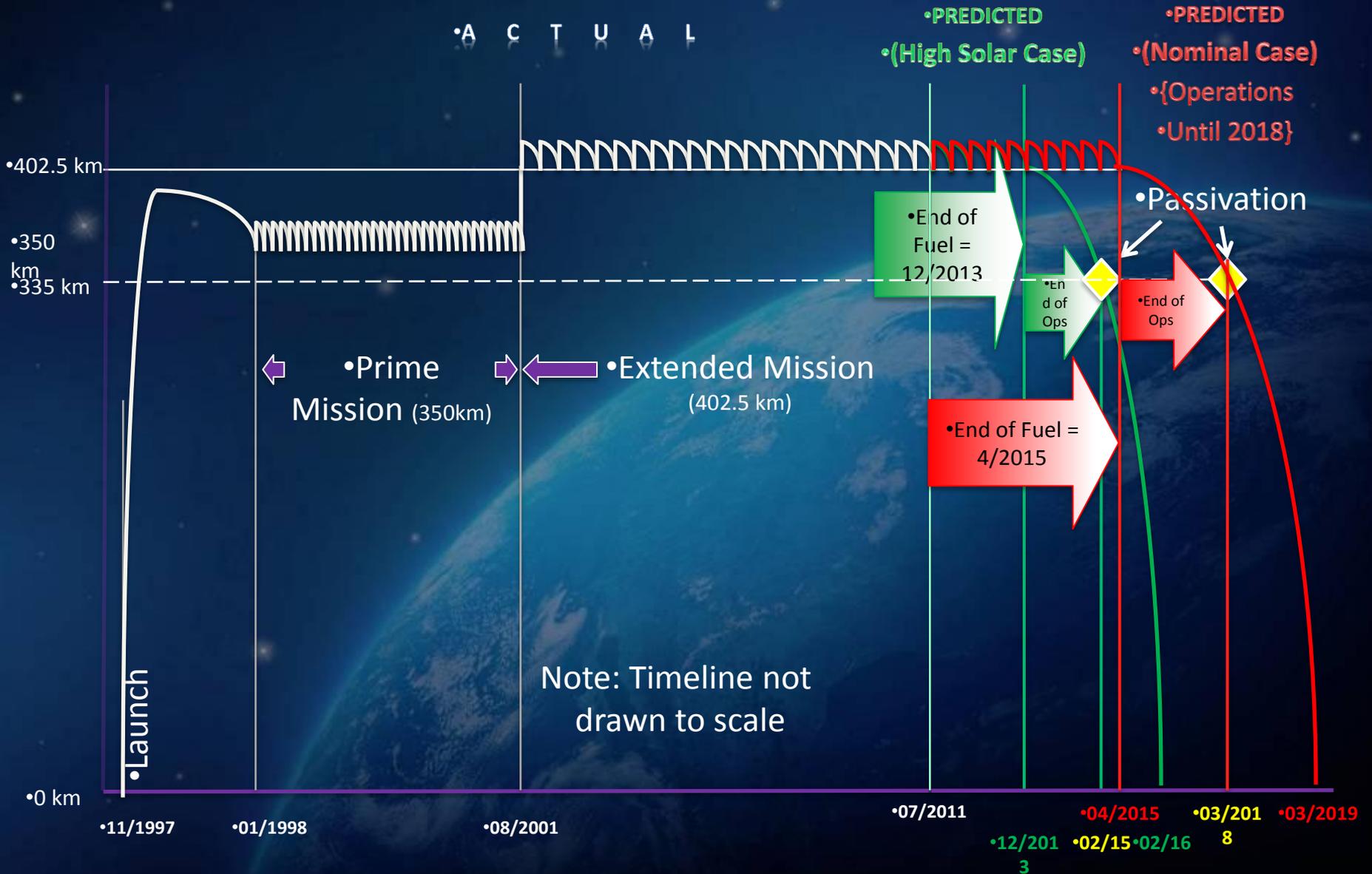
Credit: CNES/III. D. Ducros

– TARANIS (Tool for the Analysis of Radiation from lightNing and Sprites)

- Launch 2015, CNES/France; nadir staring (2 cameras, 4 photometers)
- Directly compare with GLM data

– Cross-Calibration Between GLM and MTG LI (2017) (at 777.4 nm) ¹⁷

TRMM Notional Timeline



GLM Applications

- GLM – Lightning mapping, alerts
- GLM + ABI – Severe and high impact weather
- GLM + ABI + GPM- Precipitation
- GLM + NWP – Data Assimilation
- GLM Fused
 - CI, Severe Storms, WoF, Tropical Cyclones, Multi-sensor Precipitation, Aviation Weather, Fire Weather, NOx, Volcanic Eruptions, Extreme Weather and Climate Variability
 - with Radar, Ground-Based Lightning (CG, IC), NWP



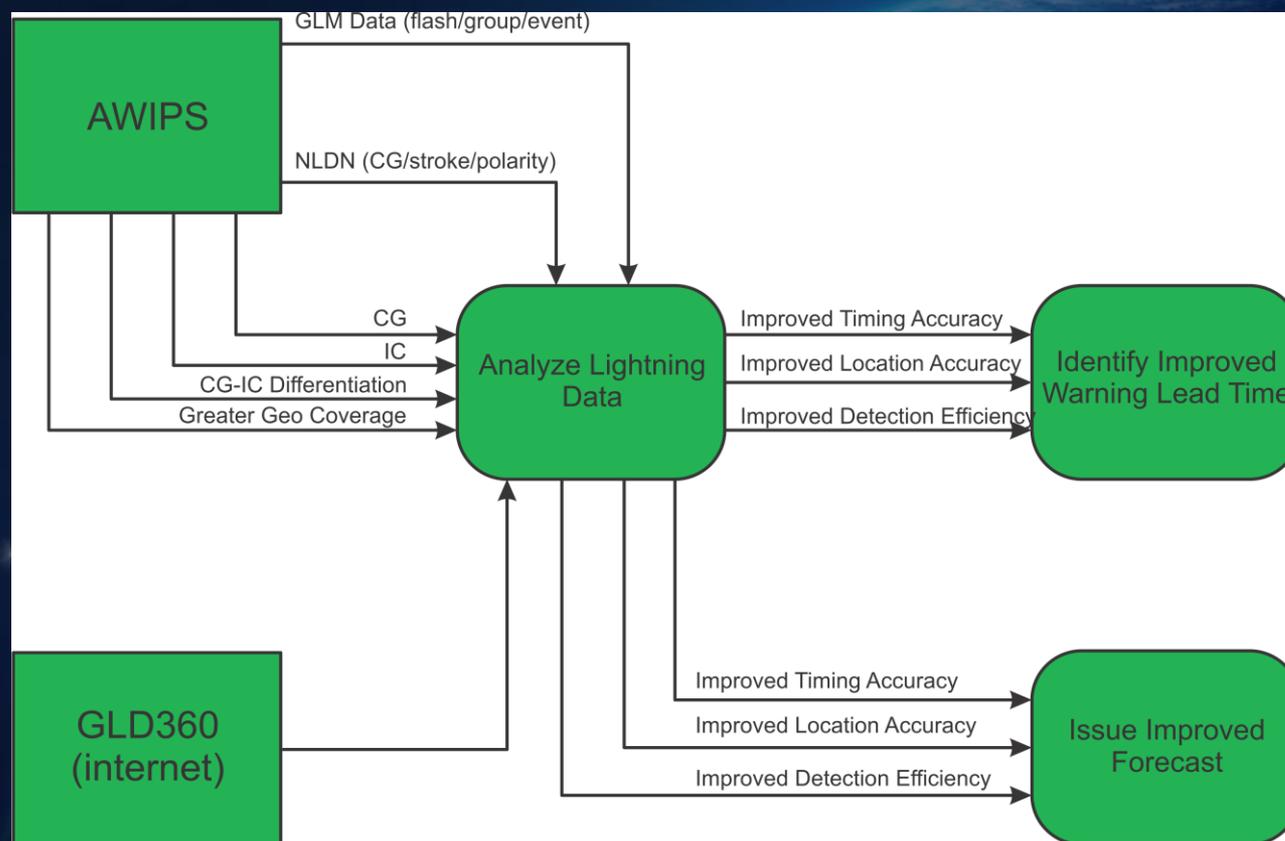
Concept of Operations and Operational Requirements:

*Lightning Data Program (05-033)

- **Current State of Lightning Operations**
 - NLDN for CONUS and surrounding areas
 - 1-minute product
 - CG data
 - Some IC data
 - GLD360 for worldwide lightning (known uneven coverage)
 - Not displayed in AWIPS
 - Hurricane data (Pacific & Atlantic)
- **Proposed Concept of Lightning Operations**
 - NLDN for CONUS and surrounding areas (same as Current)
 - GLM total lightning
 - Total lightning over GLM FOV
 - Use AWIPS-II
 - Plot total lightning data
 - Monitor total lightning trends
 - Use data to obtain more detailed information (database query)
 - Archive lightning data

NWS Concept of Operations and Operational Requirements Lightning Data Program (05-033)

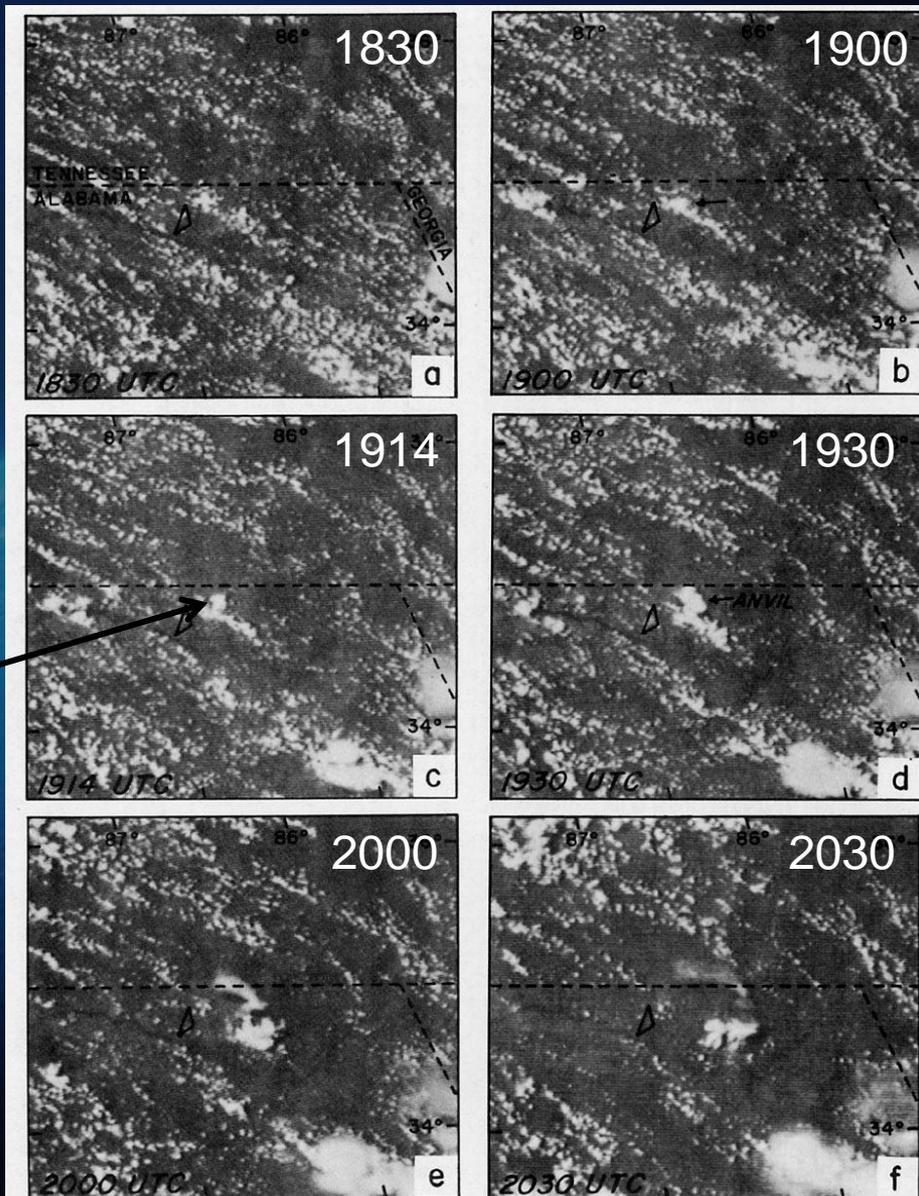
- GLM Will Add Major Total Lightning Data Source to the Operational Pallet of Resources



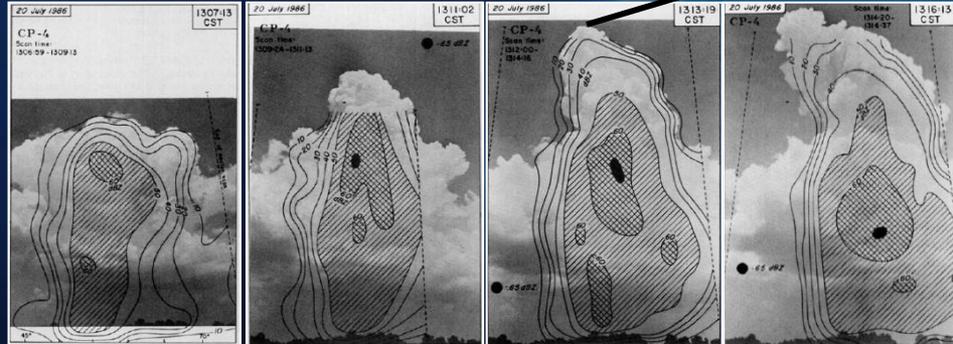
Severe Storm Operations and Decision Aids

- **Small Air Mass Thunderstorm**
 - Huntsville “Monrovia” Microburst, 20 July 1986
 - Pulse air mass storm, 65 dBZ max Z
 - Pea size hail, 40 kt outflow
 - 110 total lightning , 6 CG strikes

Cloud top temperatures continue cooling after reaching the mature stage as cirrus anvil fills imager fov

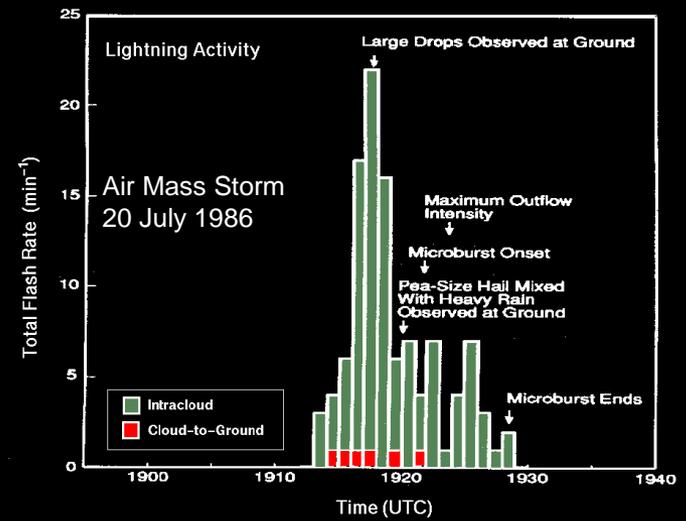


1907 1911 1913 1916



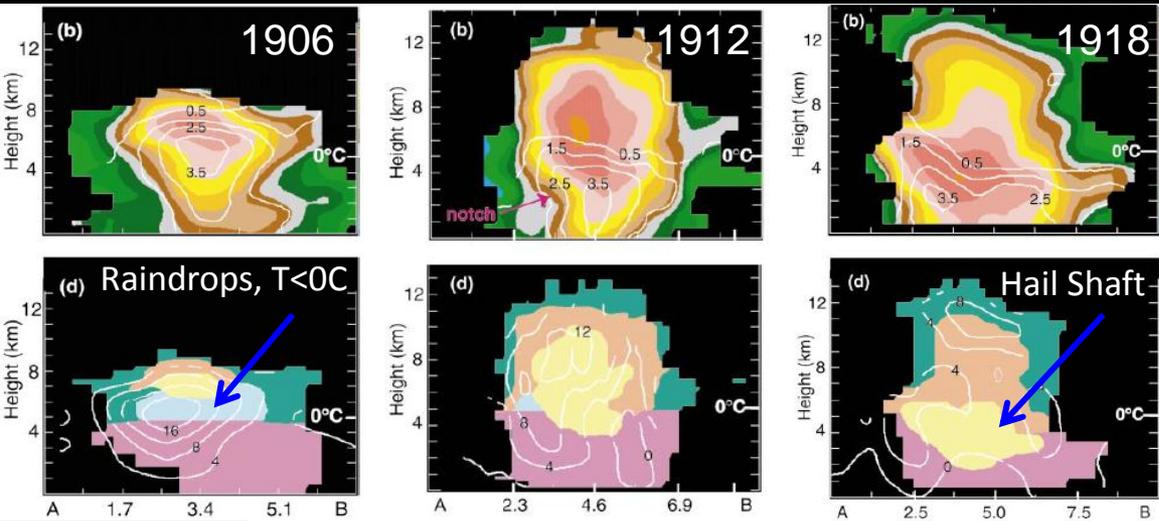
Lightning Connection to Storm Updraft, Storm Growth and Decay

- Total Lightning — responds to updraft velocity and concentration, phase, type of hydrometeors, integrated flux of particles
- Dual-Pol WX Radar — responds to concentration, size, phase, and type of hydrometeors- integrated over small volumes

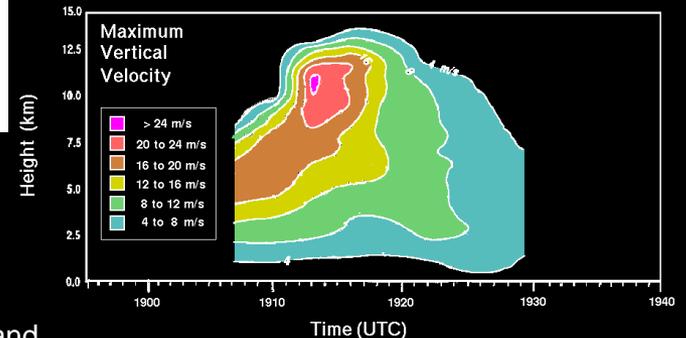
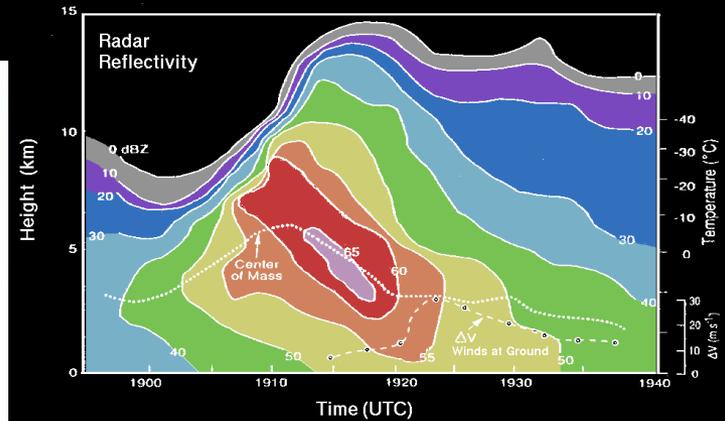
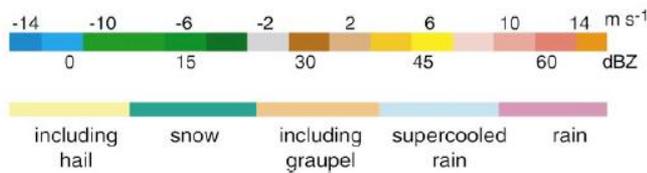


Growth, $Z_{dr} > 0$

Glaciated, $Z_{dr} < 0$



w, dBZ, HID

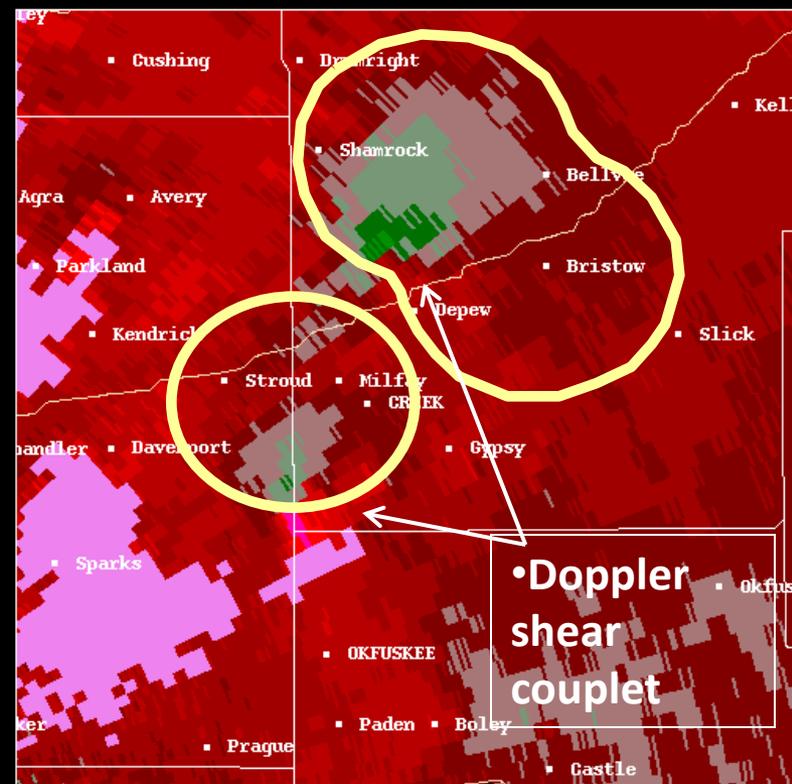
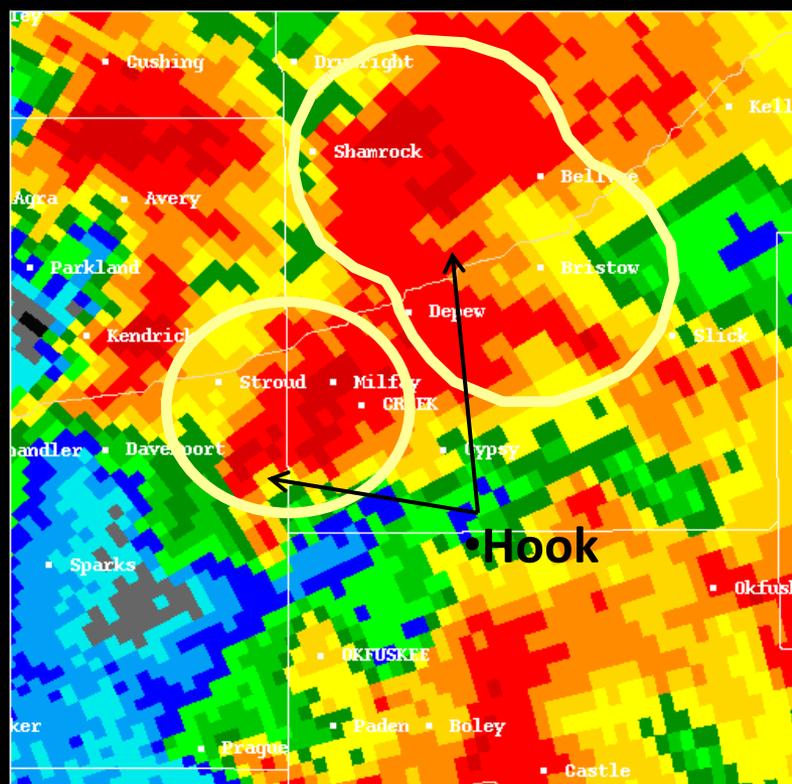


Adapted from Goodman et al, GRL, 1988; Wakimoto and Bringi, MWR, 1988; Kingsmill and Wakimoto, MWR, 1991, Zeng et al., 2001, Gatlin and Goodman, JTECH, 2010

OK Tornado Outbreak 3 May 1999

NEXRAD Reflectivity

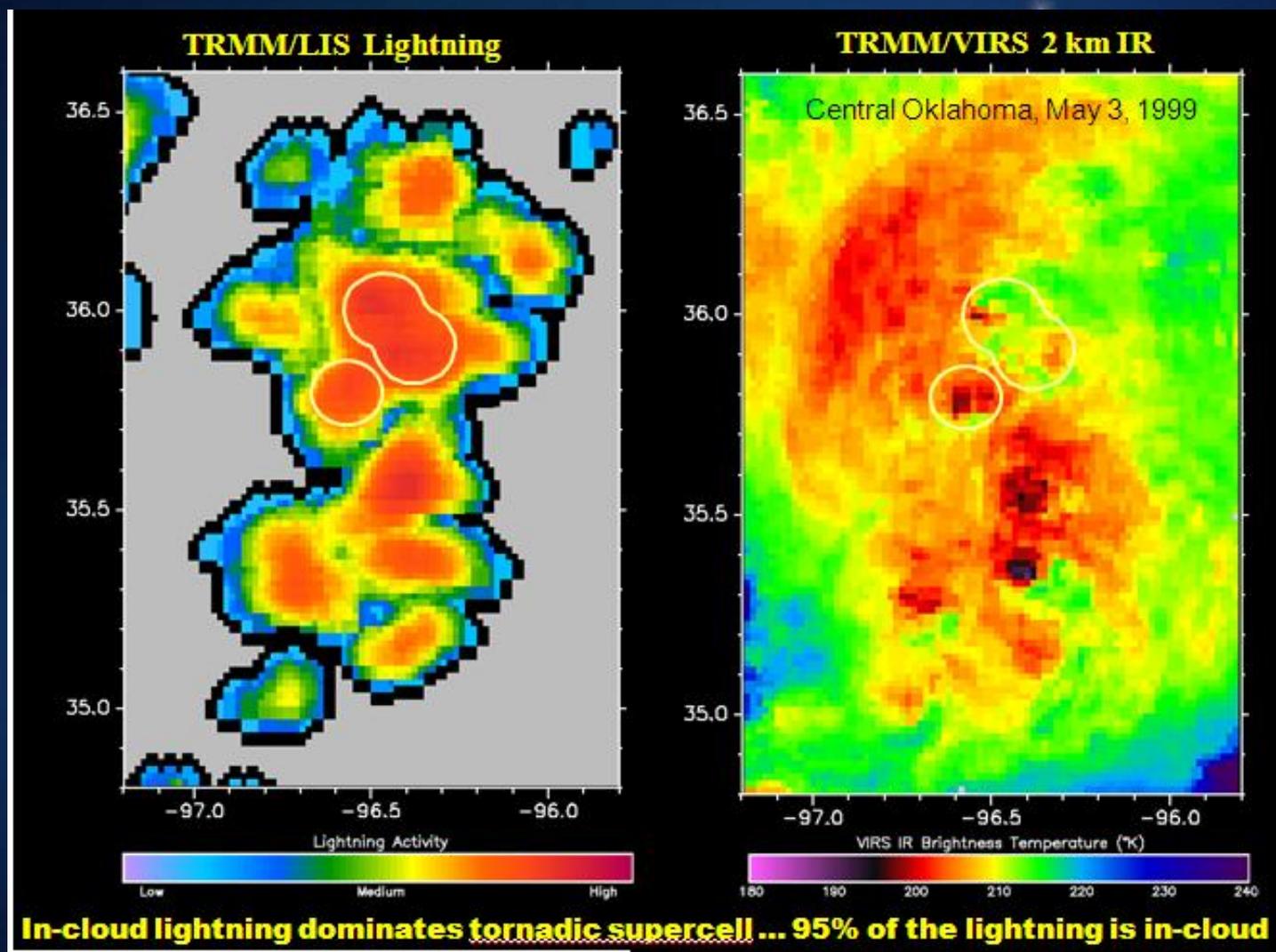
NEXRAD Velocity



Active lightning region in tornadic supercell ... correlates with radar hook echo and velocity couplet

Total Lightning Dominates During OK Tornado: 3 May 1999

GLM and ABI Combined (with radar) characterizes storm intensification and decay



Lightning Detection

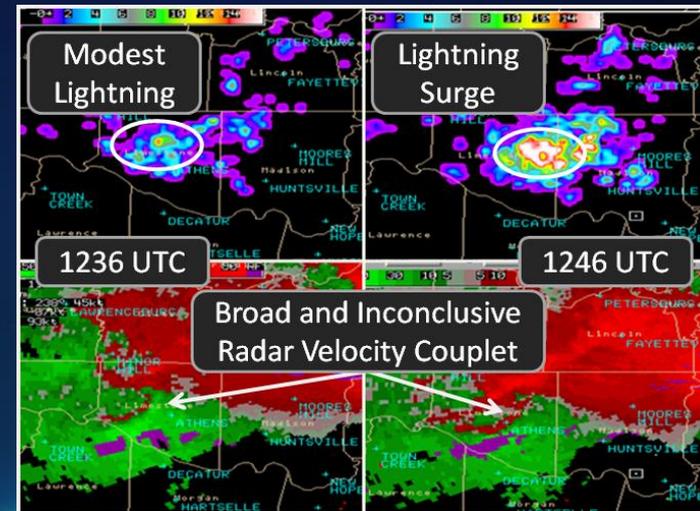
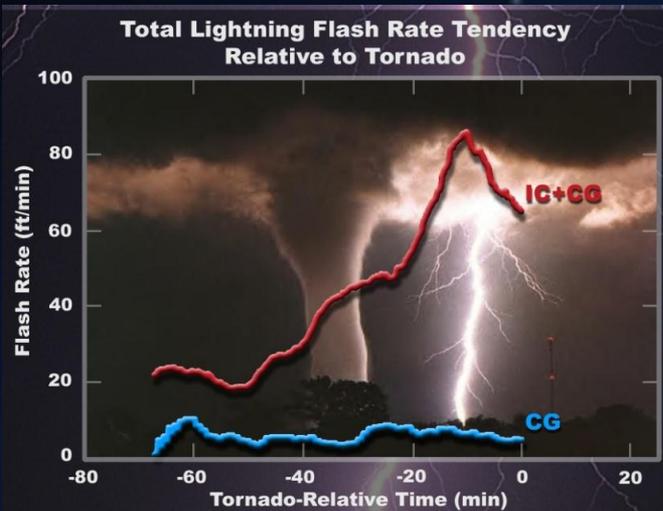


TABLE 3. Skill scores and average lead times using the sample set of 711 thunderstorms for both total lightning and CG lightning, correlating trends in lightning to severe weather.

	POD	FAR	CSI	HSS	lead time (all)	lead time (tornado)
Total lightning	79%	36%	55%	0.71	20.65 mins	21.32 mins

National Average for Tornado warning lead-time is only 14 minutes

Operational demonstration underway beginning in April 2012 of the total lightning algorithm at the Hazardous Weather Testbed (at request of NWS)

See: [Lightning Jump Algorithm and Relation to Thunderstorm Cell Tracking, GLM Proxy and other Meteorological Measurements](#) - Schultz, Carey, Cecil, Bateman



Total Lightning Demonstrations at the GOES-R Proving Ground



• Pseudo-GLM

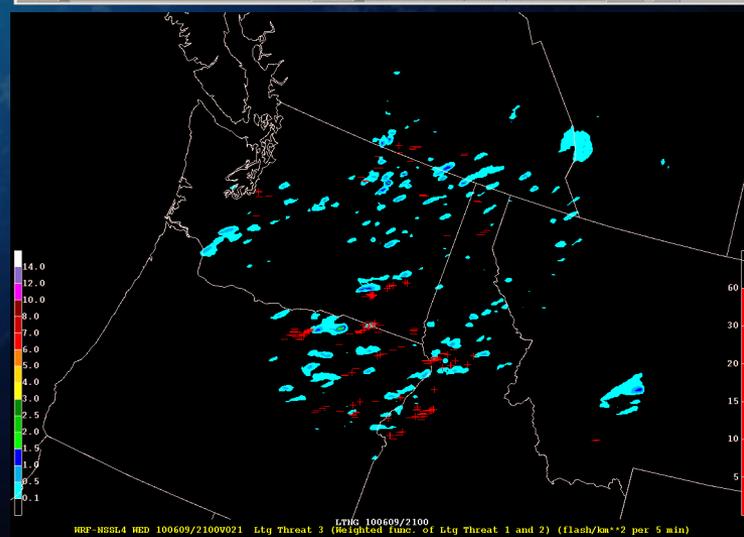
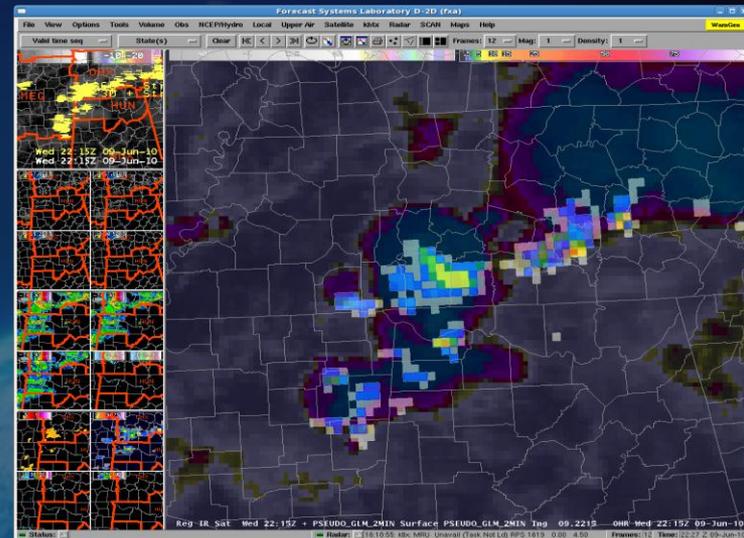
- Data from ground-based total lightning detection networks
 - Huntsville, AL; Washington, DC; Melbourne, FL; and Norman, OK
- Raw data sorted into flashes and interpolated to an 8km grid
- Running 2-minute average

• Simulated lightning threat

- Implemented in NSSL-WRF, OU/CAPS ensemble, and High Resolution Rapid Refresh (HRRR)
- Estimates total lightning from vertical ice content and flux within cloud objects (see McCaul et al., 2009)

See: The WRF Lightning Forecast Algorithm for GLM: Refinement and Incorporation into Convection-allowing Ensemble Forecasts - [Bill McCaul](#)

A lightning data assimilation scheme for the WRF-ARW model at cloud-resolving scales: Case studies - [Alex Fierro](#)





Proving Ground Forecaster Feedback: Lightning Detection

- “The total lightning data is an excellent tool for monitoring convection, I see much promise for such data in the future...”
- “I utilized it as a situational awareness product ...the PGLM data gave me more confidence in my warning.”
- “Total lightning data preceded the CG network (NLDN) anywhere from 10-40 minutes. I was able to quickly determine when flash rate was significantly increasing, and then compare with satellite and updraft/downdraft parameters for a nice big picture.”
- “Coming into the day, I wasn't quite sure when or where to or why to use the data, but after using it. I really think it has a lot of functionality and is useful in warning operations. I look forward to it as a product from the GOES-R.”

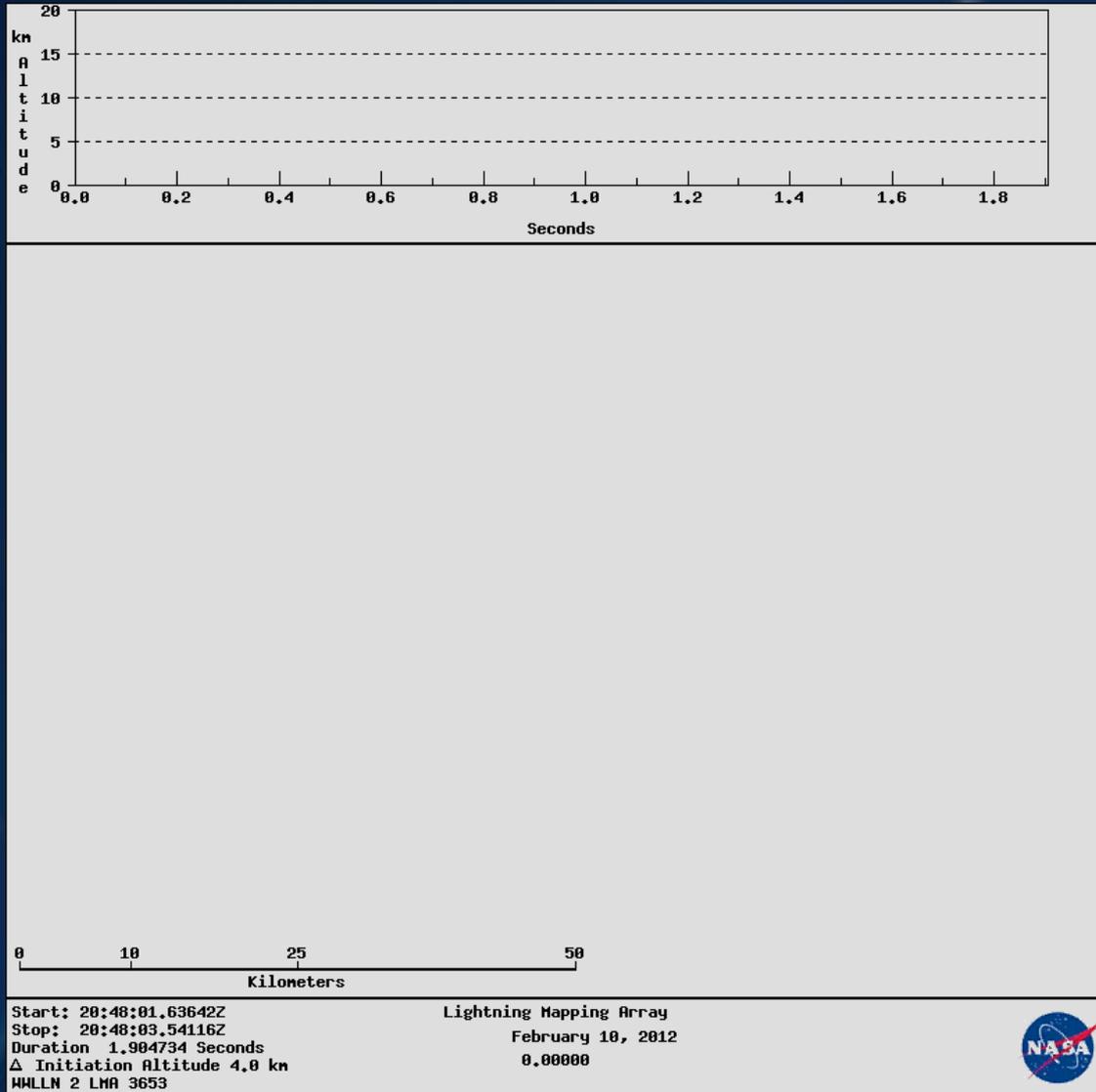
“We saw several instances where the total lightning was picking up on storms before the AWIPS lightning [NLDN] program picked up on them. One could see the utility of this in the future, bringing with it a potential for lightning statements and potentially lightning based warnings.”

-Pat Spoden (SOO, NWSFO Paducah, KY)



See: Lightning at HWT (Spring Experiment) –
Kristin Kuhlman, Chris Siewert

SPLMA, WWLLN Flash During TRMM Overpass: CHUVA 10 Feb 2012



Currently Available Training

- **VISIT CONUS Lightning**
- **VISIT Lightning Meteorology I**
- **VISIT Lightning Meteorology II**
- **COMET Intro to Tropical Met**
- **COMET Fire Weather Climatology**
- **COMET GOES-R Benefits**
- **VISIT GOES-R 101**
- **SPoRT Lightning Mapping Array**
- **SPoRT PGLM Training**
- **VISIT Use of GOES/RSO Imagery w/Remote Sensor Data for Diagnosing Severe Wx**



GLM Posters



- **Algorithm Performance**

- **The Ground Flash Fraction Retrieval Algorithm Employing Differential Evolution: Simulations and Applications** - Koshak, Solakiewicz
- **Lightning Jump Algorithm and Relation to Thunderstorm Cell Tracking, GLM Proxy and other Meteorological Measurements** - Schultz, Carey, Cecil, Bateman
- **GOES-R AWG GLM Val Tool Development** - Bateman, Mach, Goodman, Blakeslee, Koshak
- **The WRF Lightning Forecast Algorithm for GLM: Refinement and Incorporation into Convection-allowing Ensemble Forecasts** - McCaul, Case, Goodman, Dembek, Kong

- **Intercomparisons**

- **Intercomparison of Lightning Location Systems during CHUVA-GLM field campaign and thunderstorm characteristics** - Albrecht, Morales, Goodman, Blakeslee, Bailey, Carey, Mach, Hall, Bateman, Rudlosky, Holler, Betz, Mattos, Nag, Said, Lojou, Heckman, Pinto Jr., Naccarato, Saraiva, Saba, Holzworth, Anderson, Collins



GLM Posters

- **Assimilations**

- **A cloud-scale lightning data assimilation technique and the explicitly forecast of lightning with full charging/discharge physics implemented within the WRF-ARW model** - Fierro, Mansell, Allen, Ziegler, MacGorman
- **Evaluating storm intensity using coupled TRMM Lightning Imaging Sensor and Meteosat Second Generation in preparation for GOES-R** - Jewett, Leroy, Mecikalski, Walker
- **Utility of GOES-R GLM observations using hybrid variational-ensemble data assimilation in regional applications** – Zupanski
- **Assimilation of lightning data in the rapid Refresh model and evaluation of lightning diagnostics from nested HRRR runs** - Hu, Alexander, Weygandt, Benjamin, Lin
- **Integrated GOES-R GLM/ABI approaches for the detection and forecasting of convectively induced turbulence (CIT)** - Carey, Feltz, Bedka, Monette, Wang, Rogers, Scott
- **Combining GLM and ABI for Enhanced GOES-R Rainfall Estimates** - Adler, Xu, Wang



Summary

- GLM Instrument Development on Track- FM1 2013
- Code Development on Track & Within Specifications
- Proxy data and Cal/Val tools in development for monitoring GLM performance
- GLM Data will enhance future NWS Products
- Training content and module development coordination with NWS, COMET, VISIT
- For more details, please visit GLM posters