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

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GOES-R AWG Lightning Detection Team

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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
Geostationary Lightning Mapper (GLM)

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
GLM Sensor Unit Overview

- Baffle Support
- Solar Rejection Filter
- Solar Blocking Filter
- Baffle & Door
- Narrow Band Filter
- Lens Housing & Support Structure
- Variable Pitch CCD
- Focal Plane Array Assembly (FPAA)
- Loop Heat Pipes (FPAA) and Thermal Straps (SEB)
- Metering Tube
- 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
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

Courtesy, Rachel Albrecht
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)
  - **TARANIS (Tool for the Analysis of RAdition 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)
TRMM Notional Timeline

- **Prime Mission (350 km)**
- **Extended Mission (402.5 km)**
- **End of Fuel = 12/2013**
- **End of Ops**
- **End of Fuel = 4/2015**
- **Passivation**

**Note:** Timeline not drawn to scale
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

*Source: NWS/Sergio Marsh*
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
Added GLM Value for 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

From Wakimoto and Bringi, 1988; Photos, K. Knupp
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

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

In-cloud lightning dominates tornadic supercell ... 95% of the lightning is in-cloud
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.

<table>
<thead>
<tr>
<th></th>
<th>POD</th>
<th>FAR</th>
<th>CSI</th>
<th>HSS</th>
<th>lead time (all)</th>
<th>lead time (tornado)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lightning</td>
<td>79%</td>
<td>36%</td>
<td>55%</td>
<td>0.71</td>
<td>20.65 mins</td>
<td>21.32 mins</td>
</tr>
</tbody>
</table>

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

Source, NWS/Brian Motta
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

• **Intercomparisions**
  - *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
  - 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