GLM Post Launch Product Testing Overview and Flash Energy Analyses

GLM – Sandia/LANL Technical Interchange Meeting

Sept. 10, 2019; Huntsville, AL

William Koshak, NASA/MSFC

(with PLPT results from other Cal/Val Team Members as indicated)

Overview

- PLPT Basics
- Sample PLPT GLM-16 Results
- More Details (PS-PVR Packages)
- Lightning Optical Energy Analyses

Main focus of GLM Validation

- **Flash Detection Efficiency**

  Detect 70% or more of the flashes across entire FOV, over a 24 hr period.

- **Flash False Alarm Rate**

  Flash false alarms (e.g., fake flashes due to noise) should be less than 5% across entire FOV, over a 24 hr period.

- **Location Accuracy**

  Product mapping accuracy should be under 5 km (~ ½ pixel) ; we use the mode.

- **Time Accuracy**

  GLM time tag each event to an accuracy of 1 msec.

- **Energy Benchmarking**

  To better determine potential future instrument degradation, benchmark stable Deep Convective Cloud (DCC) and lightning energies during PLPT.

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Effective Date: Date of Last Signature
Responsible Organization: GOES-R Ground Segment/Code 416

416-R-RIMP-0313
Version 1.2

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE-R SERIES
GOES-R
NOAA ~ NASA

Geostationary Operational Environmental Satellite (GOES) – R Series

**Geostationary Lightning Mapper (GLM)
Beta, Provisional and Full Validation
Readiness, Implementation and Management
Plan (RIMP)**

- Targets of Opportunity (TOO): VAL of a Lightning Sensor differs from VAL of typical imager; i.e. since lightning transient, VAL is restricted to TOO.
- Flash DE & FAR are Estimates: Because reference data normally doesn't detect all lightning.
- Source Physics: GLM detects in the optical (near-IR) and many of the reference datasets are in the RF. (e.g., LMAs see discharge breakdown in the VHF that might not show up in optical → apple/orange).
- Source Scattering: Optical is cloud-scattered, but cloud is transparent to radio. So often see GLM detections near cloud edges where no radio sources.
- ISS/LIS & FEGS are Critical: More of an apple/apple comparison w/GLM.

The RIMP

Provides Val Principles and Details the PLPTs (Post Launch Product Tests)

Reference Datasets

Data Name	Data Available	Data From
ATDnet	MOU	UK Met Office
BrazilDAT	MOU	INPE
ENTLN	In-house	Earth Networks
GLD360	In-house	Vaisala
LINET (national)	in-house	Nowcast
NLDN	In-house	Vaisala
RinDAT	MOU	INPE
STARnet	MOU	Univ. Sao Paulo
NALMA*#	In-house	NASA Server[6]
TLMA	MOU	Environment Canada
DCLMA	In-house	NASA Server[6]
FCLMA	MOU	Colorado State Univ.
NGLMA	MOU	Georgia Tech.
HLMA	MOU	TAMU
KSCLMA*	MOU	NASA Server[6]
NMLMA*	MOU	New Mexico Tech.
OKLMA*	MOU	OU-CIMMS
WTLMA	MOU	Texas Tech.
WILMA	In-house	NASA Server[6]
*INTF	MOU	New Mexico Tech
#LINET (local)	In-house	Nowcast

Data Name	Data Available	Data From
ABI	In-house	NASA Server[6]
NEXRAD Radar	MOU	NOAA-NWS
MSG SEVERI	MOU	EUMETSAT
WWLLN	In-house	Univ. of Washington
AGS	In-house	UAH, MSFC
ISS-LIS	In-house	NASA Server[6]
TARANIS[4]	MOU	CNES
HAMMA	In-house	UAH
KSCFMA	MOU	NASA Server[6]
Laser Beacon	TBD	TBD
Landmarks[7]	TBD	TBD
ISS-LIS Backgrounds	In-house	NASA Server[6]
TRMM-LIS Backgrounds[3]	In-house	NASA Server[6]
TRMM-LIS[3]	In-house	NASA Server[6]

The PLPTs

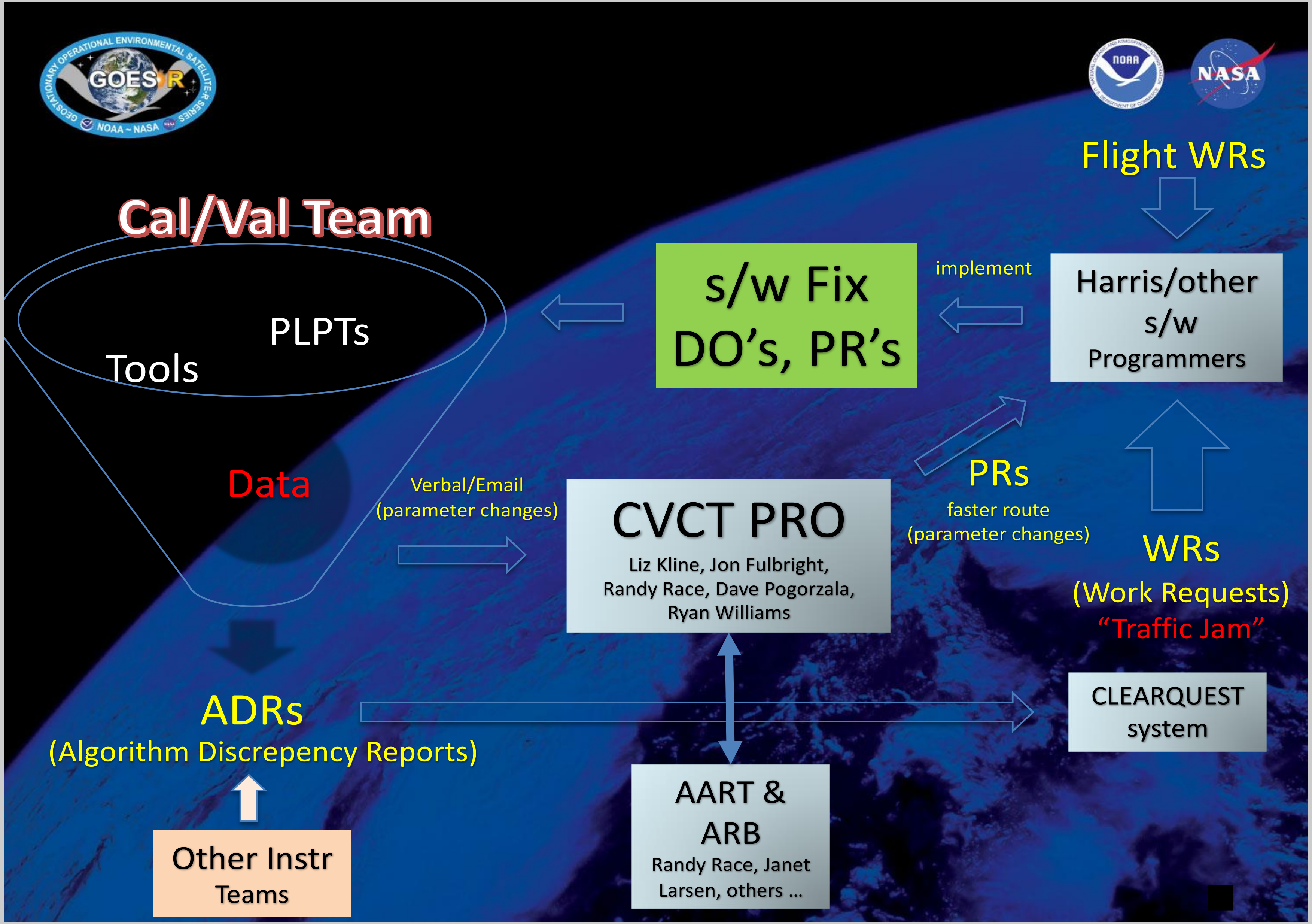
Test ID	Abbreviated Test Titles for GLM
PLPT-GLM-001	Validate DE/FAR using med/long-range networks (e.g., NLDN, EN, GLD360)
PLPT-GLM-002	Validate DE/FAR using short-range networks (e.g., LMAs)
PLPT-GLM-003	Validate Storm DE and Storm FAR using very long range systems (WWLLN, NEXRAD)
PLPT-GLM-004	Validate DE/FAR using very short range optical systems (FEGS)
PLPT-GLM-005	Validate DE/FAR using orbit-based optical systems (e.g., ISS/LIS)
PLPT-GLM-006	Validate DE/FAR using ground-based E-field networks (e.g. HAMMA)
PLPT-GLM-009	Validate L1b-L2 Cluster/Filter by comparing w/Spec (i.e. Mach) code
PLPT-GLM-010	Validate L0-L1b Filter Algorithms by comparing w/Spec (i.e. Mach) code
PLPT-GLM-011	Validate GLM INR w/comparisons to well-located ground points
PLPT-GLM-012	Validate GLM BG DCC radiances with trendings & comparisons
PLPT-GLM-013	Validate GLM Event Energies with trendings & comparisons

MSFC/MIT-LL CWG is conducting these tests to evaluate the L2 product quality.

Full test plans and procedures are given in the GLM Readiness, Implementation, and Management Plan (RIMP v1.2; 416-R-RIMP-0313)

Item	Tool	Description	Code Language	Developer
1	VaLiD	Validate Lightning Data tool performs shallow/deep dives of GLM data using wide range of ground-based datasets discussed in RIMP.	C	Bateman/USRA
2	Cluster/Filter	In-house code for L0-L1b and L1b-L2 processing	Matlab	Mach/USRA
3	HUDAT	Huntsville Area Marx Meter Array (HAMMA) User Data Analysis Technology with emphasis on lightning energy/physics.	IDL	Bitzer/UAH
4	STROKE	STorm Retrievals frOm KSC E-Fields examines ground-based electric fields, lightning field changes, and the charges deposited by lightning in KSC, Florida.	IDL	Koshak/MSFC
5	INR/Parallax	Validates GLM INR with comparisons to well-located ground points and employs GLM background images & lightning, ABI background images, and Laser beacon data	IDL	Buechler/UAH
6	TT/DCC	Trending Tools for long-term trending of Deep Convective Clouds.	IDL	Buechler/UAH
7	TT/Lightning	Trending Tools for long-term trending of lightning counts, flash duration, and lightning energy.	IDL	Buechler/UAH Koshak/MSFC
8	LMT	24/7 Lightning Monitoring Tool (aka "Product Monitor") that alerts of problematic GLM performance	TBD	Product Area Lead
9	CompareLLS	Compare Lightning Location System tool performs shallow/deep dives of GLM data using wide range of ground-based datasets discussed in RIMP.	Matlab	Cummins, UA
10	XLMA	X Lightning Mapping Array tool for making standard 4-D plots of flashes.	IDL	Krehbiel & Rison of NMT
11	lmatools	Analyzes LMA data [sort VHF source data into flashes; calculate flash areas, volumes, and channel lengths; produce gridded products; time series statistics of flash rate and size data; simulate LMA performance].	Python	Bruning/TTU
12	FEGST	Fly's Eye GLM Simulator Tool: Data acquisition, display, storage software, and s/w for analyzing FEGS data & inter-comparing it with other lightning optical datasets (e.g. GLM, ISS/LIS).	IDL	Quick/NPP
13	ADTs	Ancillary Dataset Tools will be developed for processing datasets such as ABI, NEXRAD, SEVERI, WWLLN; some of these tools will be piggybacked to VaLiD.	Matlab & McIDas scripts	Mach/USRA Bateman/USRA
14	SITs	Specialized Impromptu Tools written “on-the-fly” to handle any analyses that are needed, but that were unexpected.	C, IDL, Matlab, Mathematica	Cal/Val Team
15	LATA	Location And Time Accuracy (LATA) Tool: Produces a variety of plots/histograms that characterize the overall location/time accuracy of GLM flashes/groups/events.	Matlab	Virts/NPP

Software tools for carrying out the PLPTs



ADR to WR

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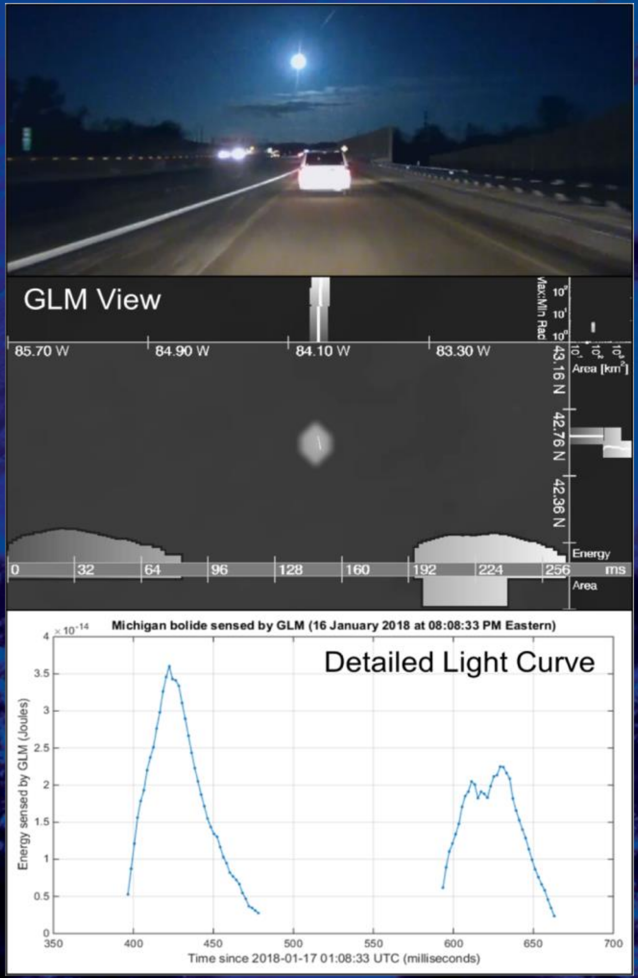
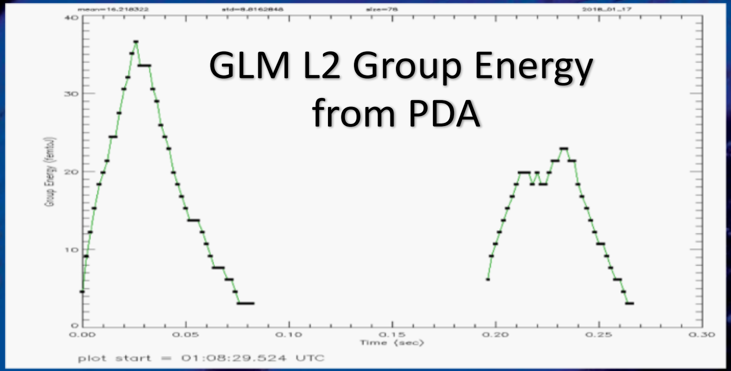
- Peter Jenniskens et al.,: Detection of meteoroid impacts by the GLM on the GOES-16 satellite, *Meteoritics & Planetary Science*, 1-25, 2018.
- Peter Brown et al., 2019: The Hamburg meteorite fall: fireball trajectory, orbit, and dynamics, *Meteoritics & Planetary Science*, 1-19, doi:10.1111/maps.13368.
    - ADR Analyses: Problem discovered by Koshak in comparing LMATC/Rudlosky Jan 2018 Michigan Bolide to PDA data.

From Rudlosky/LMATC/Peterson:





Sample (ADR 738) Poor low-end Resolution in PDA Stream

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Flash DE
(Monte Bateman/USRA)

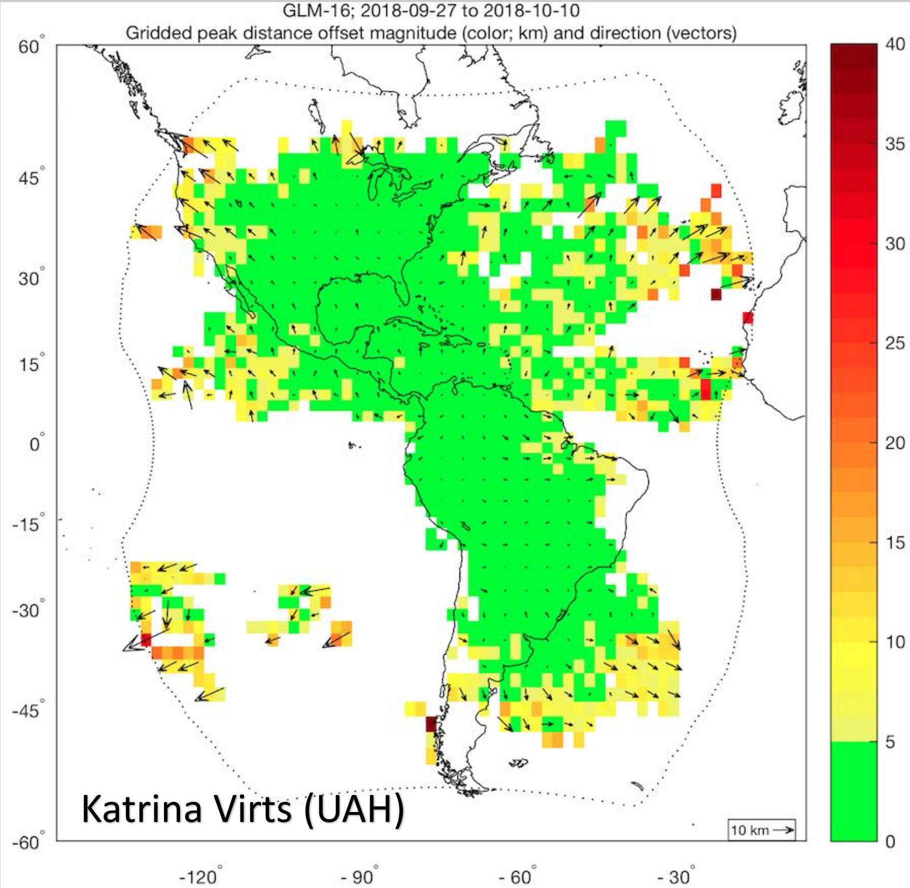
Period (2018)	GLM16 vs. GLD360			GLM16 vs. Combined Ground Networks		
	Flash DE	Flash DE (day)	Flash DE (night)	Flash DE	Flash DE (day)	Flash DE (night)
Jan	**0.84**	**0.79**	**0.89**	**0.75**	**0.71**	**0.81**
Feb	**0.83**	**0.76**	**0.88**	**0.72**	**0.69**	**0.78**
Mar	**0.83**	**0.79**	**0.88**	**0.72**	**0.71**	**0.79**
Apr	**0.82**	**0.79**	**0.87**	**0.75**	**0.75**	**0.80**
May	**0.80**	**0.78**	**0.84**	**0.74**	**0.74**	**0.80**
Jun	**0.80**	**0.76**	**0.84**	**0.75**	**0.78**	**0.82**
Jul	**0.78**	**0.77**	**0.83**	**0.76**	**0.77**	**0.84**
Aug	**0.80**	**0.79**	**0.85**	**0.74**	**0.79**	**0.79**
Sep	**0.85**	**0.83**	**0.89**	**0.77**	**0.77**	**0.82**
SFGL2 (Sep26-Oct24)	**0.85**	**0.81**	**0.88**	**0.78**	**0.74**	**0.82**

Flash Detection Efficiency

Location and Timing Error

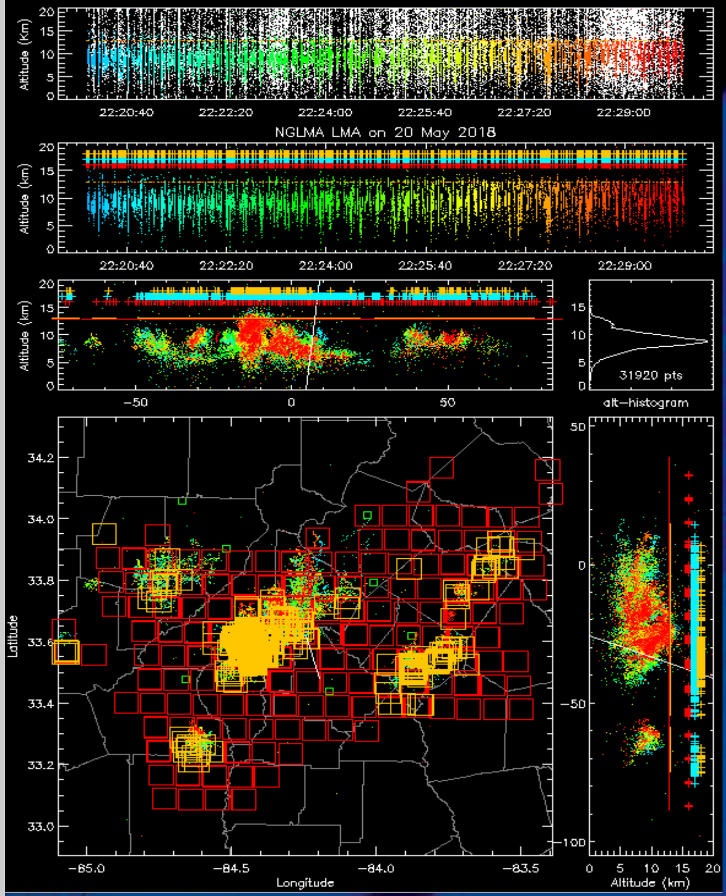
Location/Time Accuracy Katrina Virts (now w/UAH)

Period (2018)	Peak Location Accuracy (km)	Peak Timing Accuracy (ms)
Jan	3.5	-0.6
Feb	3.5	-0.4
Mar	3.5	-0.6
Apr	3.0	-0.6
May	3.0	-1.0
Jun	3.0	-0.6
Jul	3.0	-1.0
Aug	3.0	-1.0
Sep	3.0	-0.6
Sep26-Oct10	3.0	-0.8



NGLMA Analysis Deep Dive
(John Trostel/Ga Tech)

May 20, 2018 - NGLMA and GLM16 for 22:20-22:30



	GLM16
Flashes	312
Events	12,306
Offset-lon (km)	0.30
Offset-lat (km)	3.52
DE for lma flashes > 10 pts	71%
DE for big lma flashes w/≥ 75 pts	90%
DE for bigger lma flashes w/≥ 200 pts	97%
DE for medium lma flashes w/11-74 pts	65%

“pts” = # of VHF sources

Local Deep Dives

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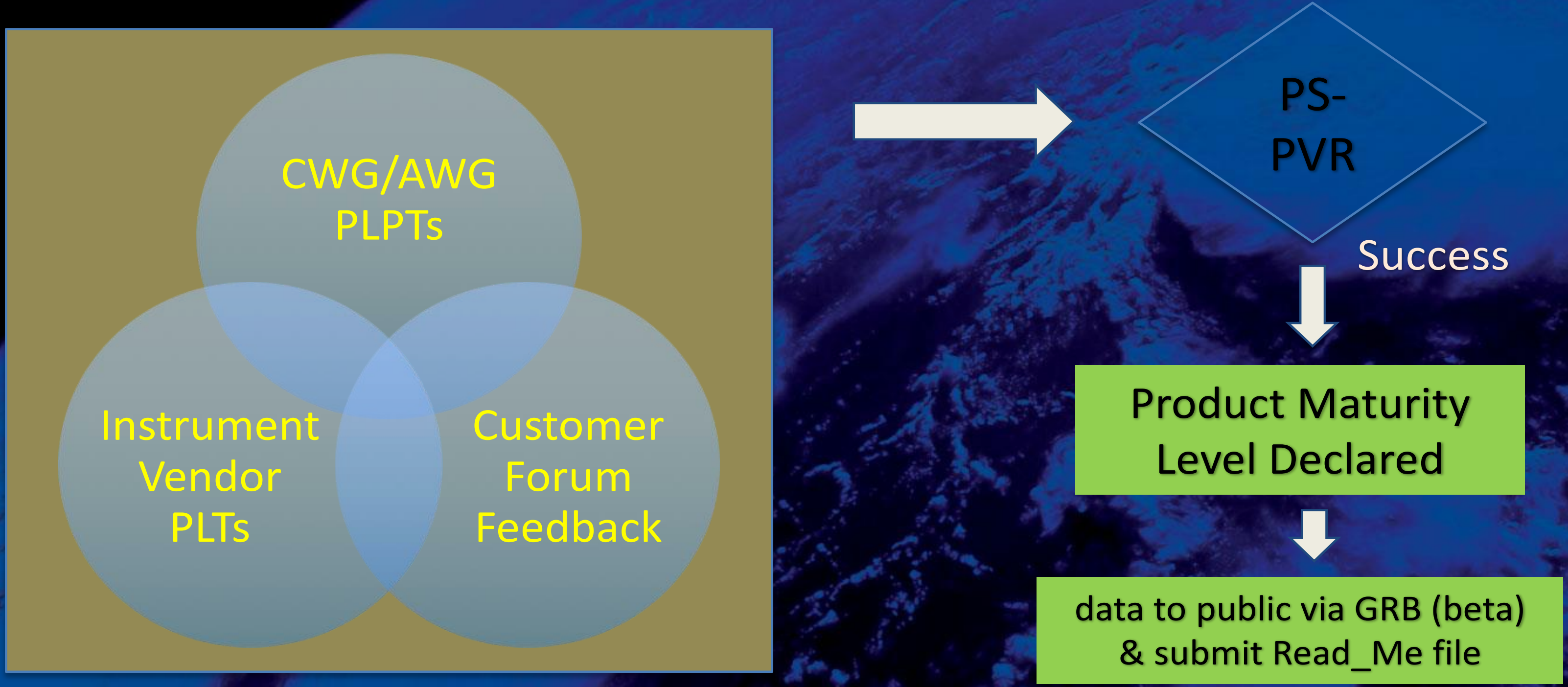
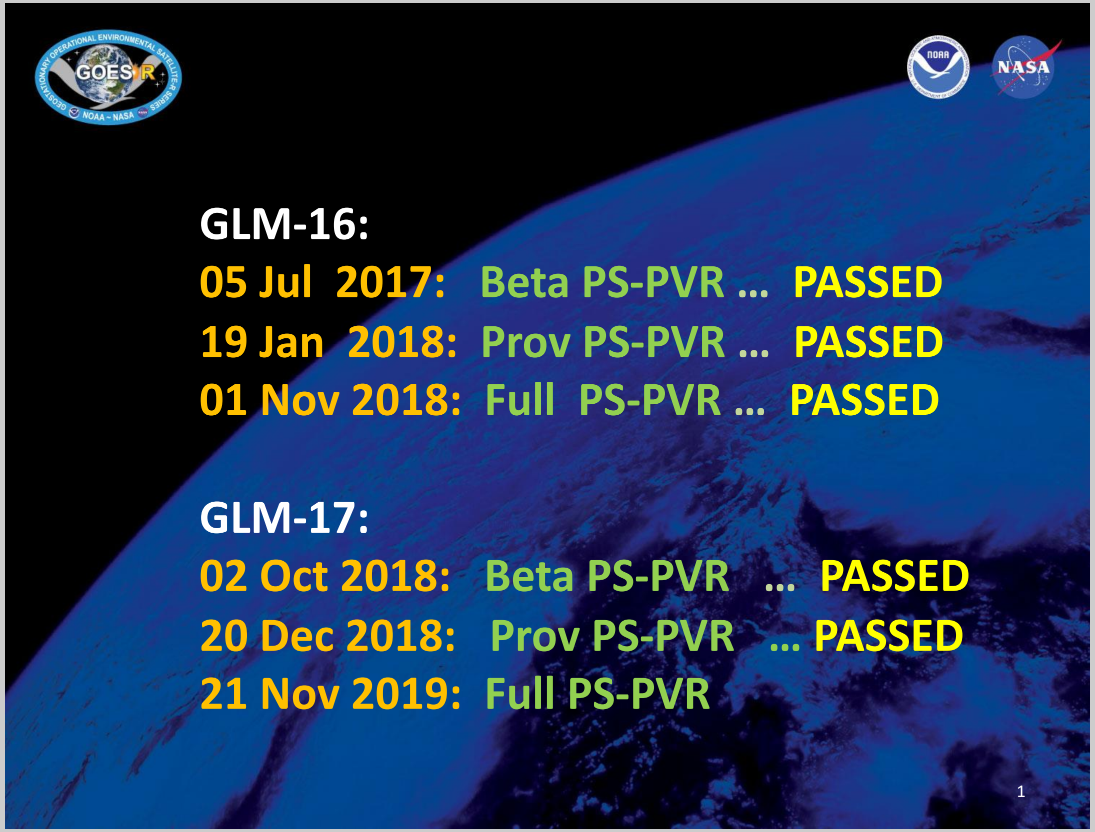
PS-PVR

- PS-PVR = Peer Stakeholder - Product Validation Review
- Assesses product quality relative to Program definitions
- Decides if products achieved **Product Maturity Level (beta, provisional, or full)**
- Provides guidance on work expected to achieve the next maturity level

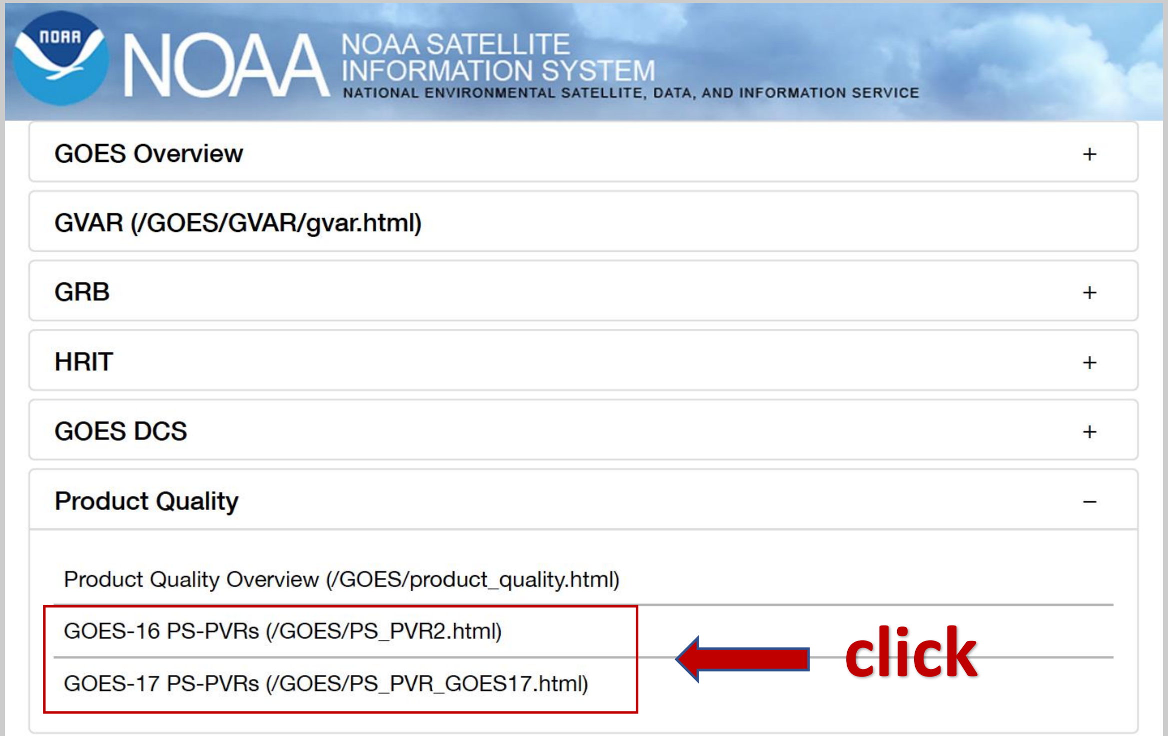


Status



More Details …

https://www.noaasis.noaa.gov/GOES/product_quality.html



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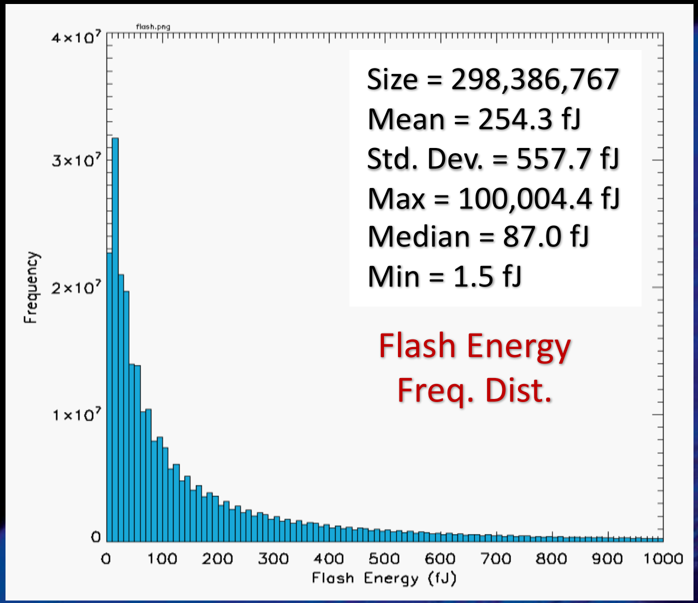
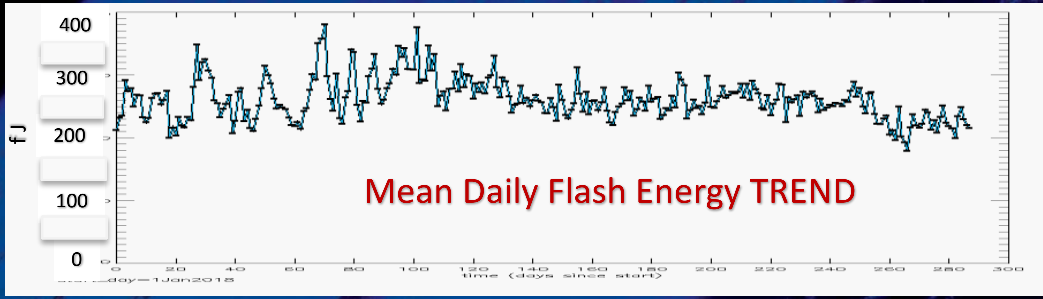
Flash Energy

(Koshak/MSFC)





- Analysis Period: 2018: Jan 1 – Oct 15 (9.5 months)
- Almost 300 M flashes
- removed flashes with flash_quality_flag ≠ 0 to help remove high-bias from blooming/glint
- Mean of 254.3 f J well in range of expectation based on heritage LIS obs.

1

Flash Optical Energy

Sample GLM16 PS-PVR Full

Gives Baseline Energy to Help Determine if Future Instrument Degradation Occurs

… will show updates to trend tomorrow

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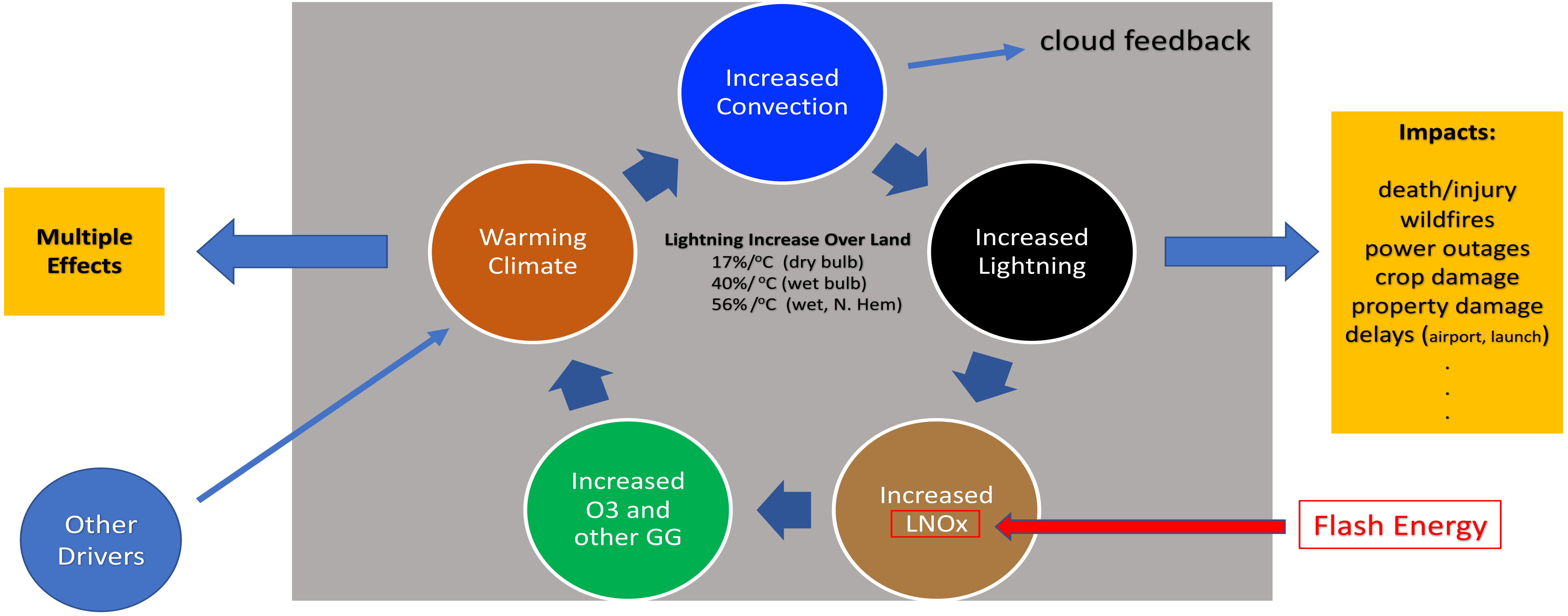
Note: Finny et al. (2018) projects a *decrease* of lightning with warming climate, so the positive feedback shown here is debatable.

Lightning Optical Energy Is a Proxy to Total Flash Energy which in turn is Important to Climate



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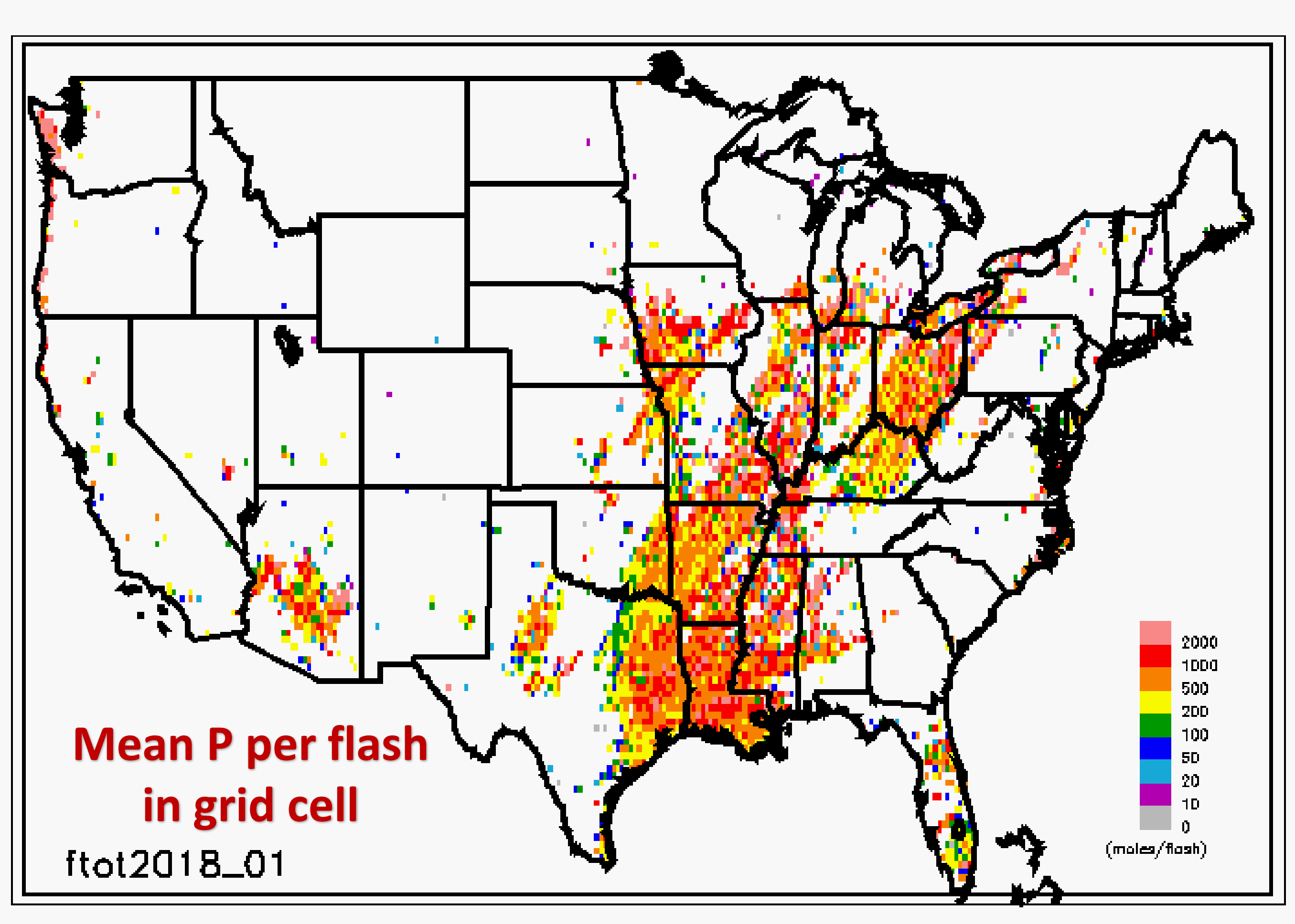
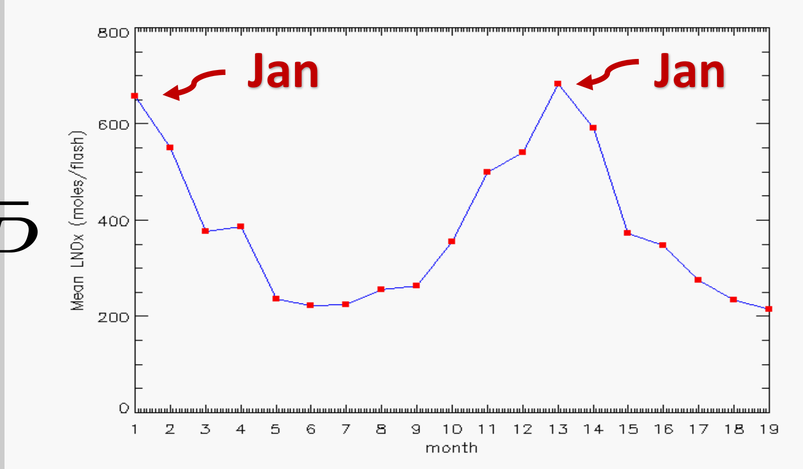
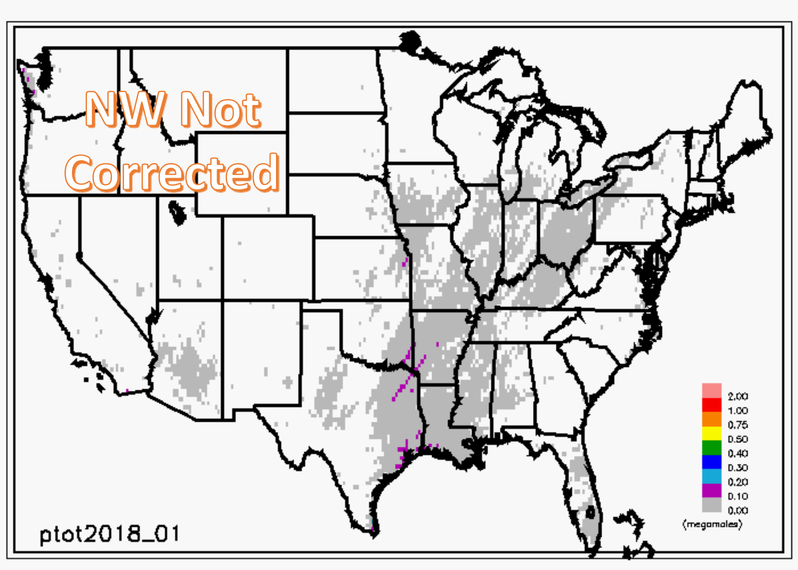
19 mo Trend (Jan2018-Jul2019) of GLM-16 CONUS LNOx Estimate

$$P = \left[\frac{Y}{\beta N_A}\right] Q \qquad \text{(in moles)}$$



$\bar{P}$





Total P from all flashes
in grid cell

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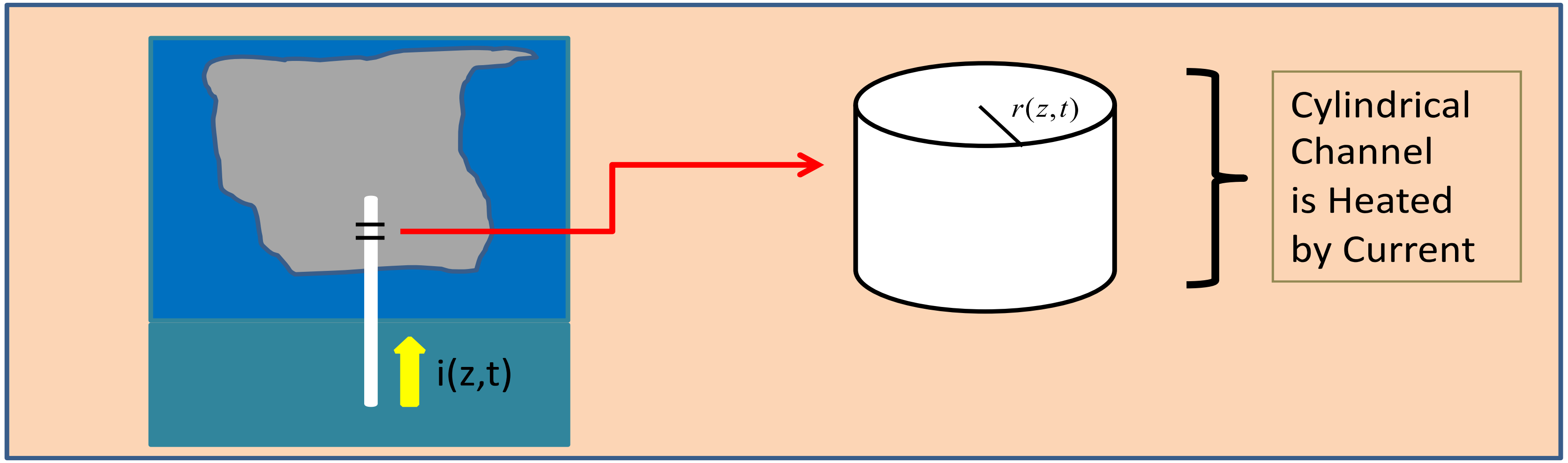
- Built a Realistic Lightning Return Stroke NOx Production Model



- Derived Governing Eq. & Applied to solve for channel radius r(z,t):

$$r^4 \frac{dr}{dt}\frac{d^2r}{dt^2} + \Gamma r^3 \left(\frac{dr}{dt}\right)^3 + \left(\frac{\Gamma}{K\rho_e}\right) r^3 \frac{dr}{dt} p_e = \left(\frac{\Gamma - 1}{2\pi^2 K \rho_e \sigma}\right) i^2$$

- Gives Channel Properties From the Radius:
  - Radial velocity (expansion rate)
  - Pressure
  - Temperature
  - Energy Density
  - Lightning Nitrogen Oxides (LNOx) Production

- **See:** Koshak, W. J., R. J. Solakiewicz, H. S. Peterson, 2015: A return stroke NO_x production model, *J. Atmos. Sci.*, **72**, No. 2, 943-954.

LNOx Return Stroke Model

GAS DYNAMIC MODEL COMBINES:

- Generalized Gas Law
- Generalized Caloric Eq. of State
- Time Derivative of 1st Law Thermo.

Solved Coupled Set of DEs for each Altitude (1 m resolution)

$$r^4 \frac{dr}{dt}\frac{d^2r}{dt^2} + \Gamma r^3 \left(\frac{dr}{dt}\right)^3 + \left(\frac{\Gamma}{K\rho_e}\right) r^3 \frac{dr}{dt} p_e = \left(\frac{\Gamma - 1}{2\pi^2 K \rho_e \sigma}\right) i^2$$

[2nd order, 1st degree, Nonlinear, Ordinary Differential Equation (ODE)]

$r = r(z,t) =$ channel radius

$i = i(z,t) =$ return stroke current

$p_e = p_e(z) =$ atmospheric pressure profile

$\rho_e = \rho_e(z) =$ atmospheric density profile

Generalized specific heat ratio: $\Gamma = 1 + G/F = 1 + (\gamma - 1)G \sim 1.14$

Specific heat ratio: $\gamma = c_p / c_v \sim 1.22$

Coefficient of resistance: $K = 2/(\Gamma + 1) \sim 0.935$

Channel conductivity: $\sigma \sim 2.2 \times 10^4\ S/m$

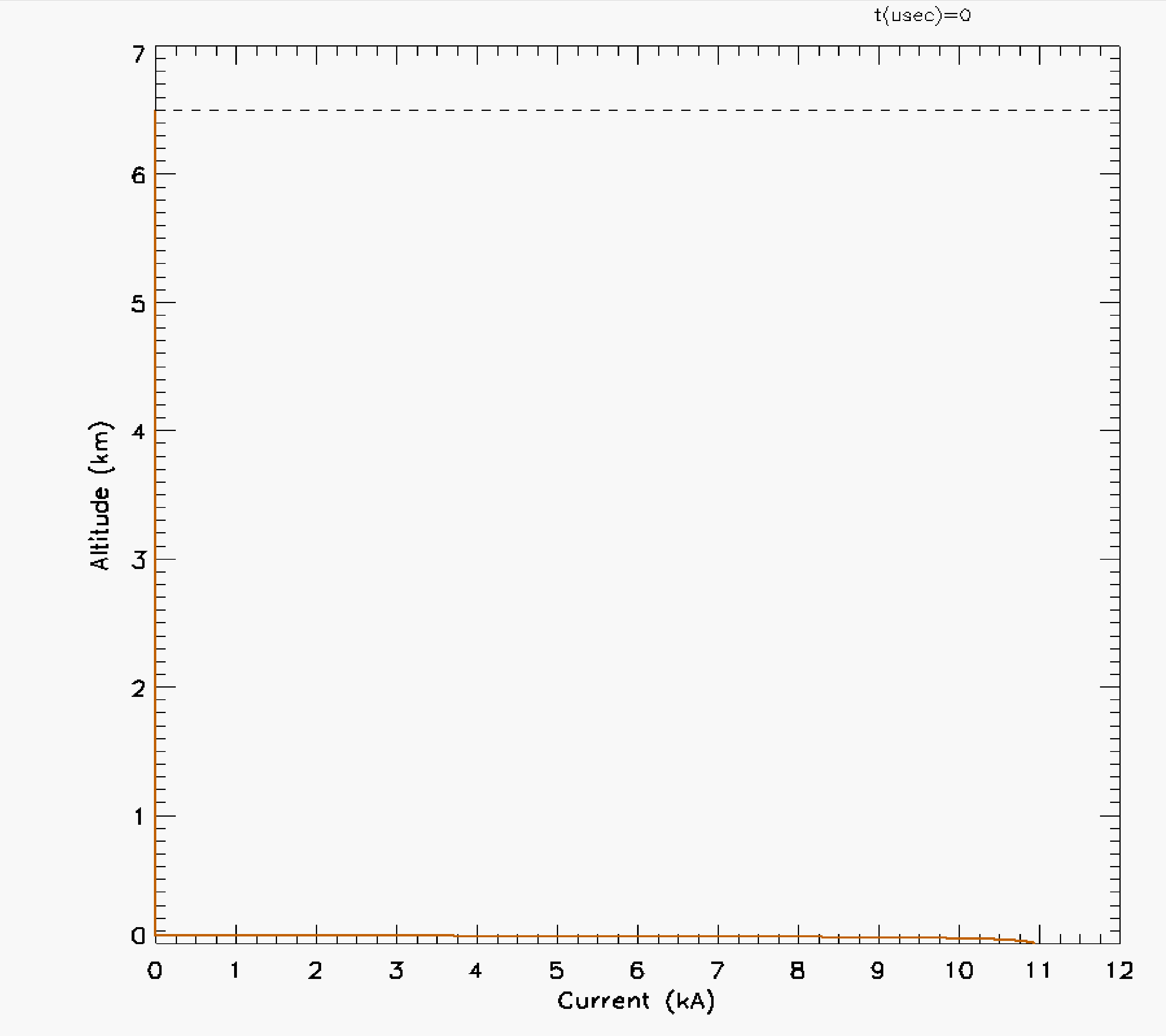
More details on the DE

$$i(z,t) = \left\{ \frac{I_{o1}(t'/\tau_1)^2 e^{-t'/\tau_2}}{\eta[(t'/\tau_1)^2 + 1]} + I_{o2}(e^{-t'/\tau_3} - e^{-t'/\tau_4}) \right\} e^{-z/\lambda}$$

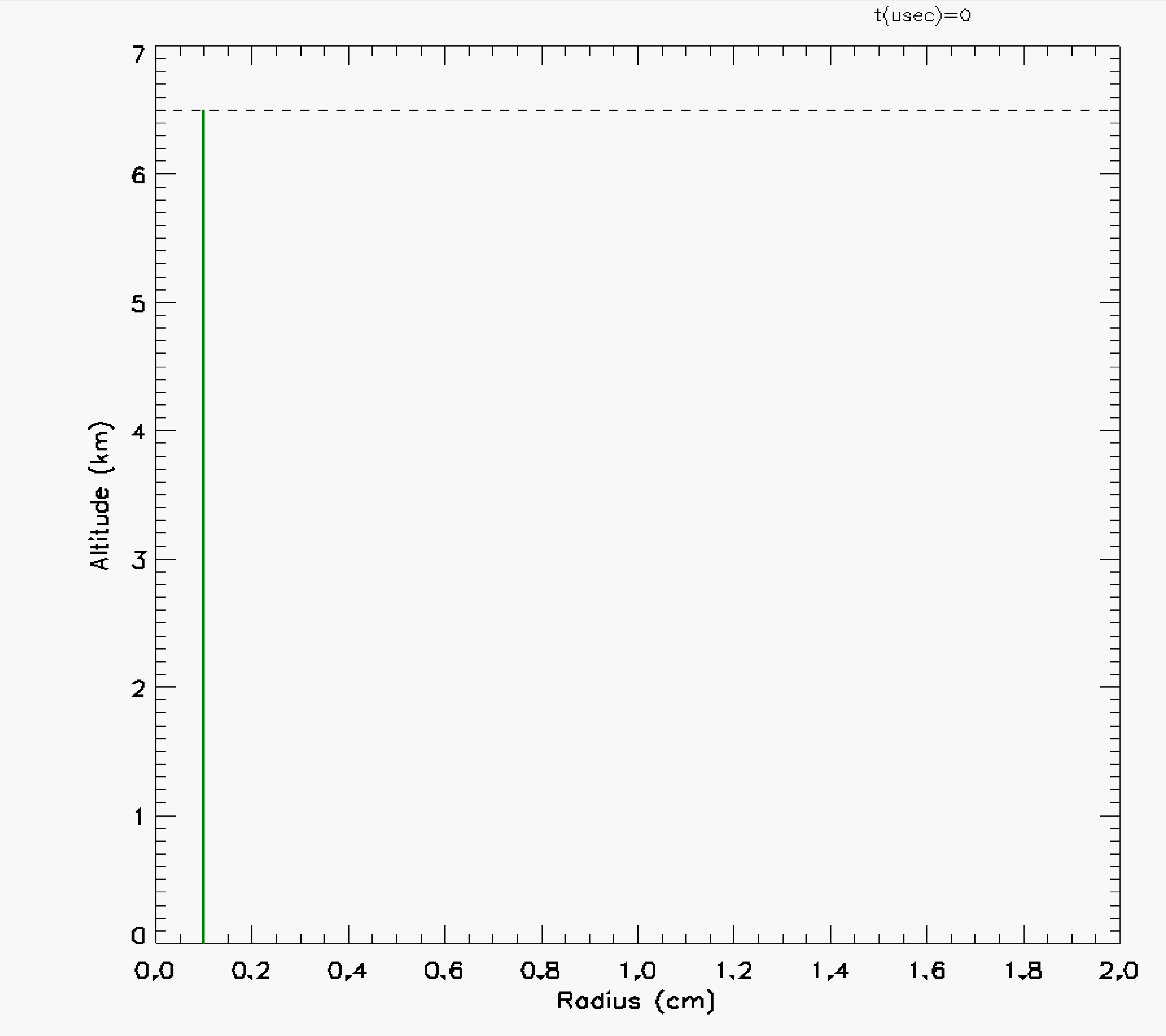
$$T_e(z) = \left[T_e^2(0) - \frac{2gAz}{R_d} \right]^{1/2} \quad \text{and}$$

$$p_e(z) = p_e(0) \exp\left\{ -\frac{T_e(0)}{A} + \left[\frac{T_e^2(0)}{A^2} - \frac{2gz}{AR_d} \right]^{1/2} \right\}.$$

$$\rho_e(z) = \frac{p_e(z)}{R_d T_e(z)}.$$



Input Channel Current



Output Channel Radius

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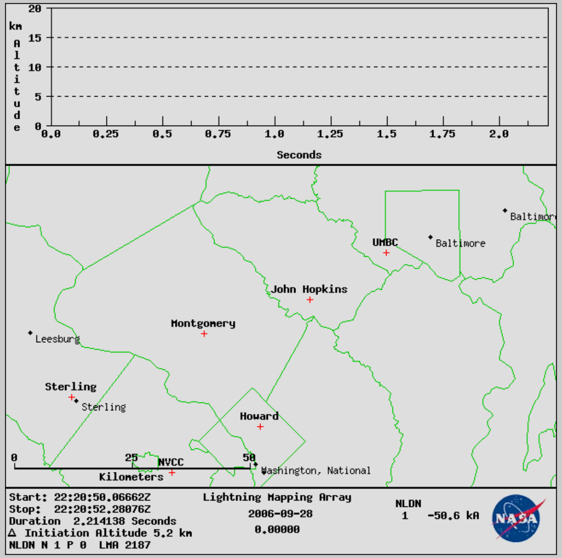
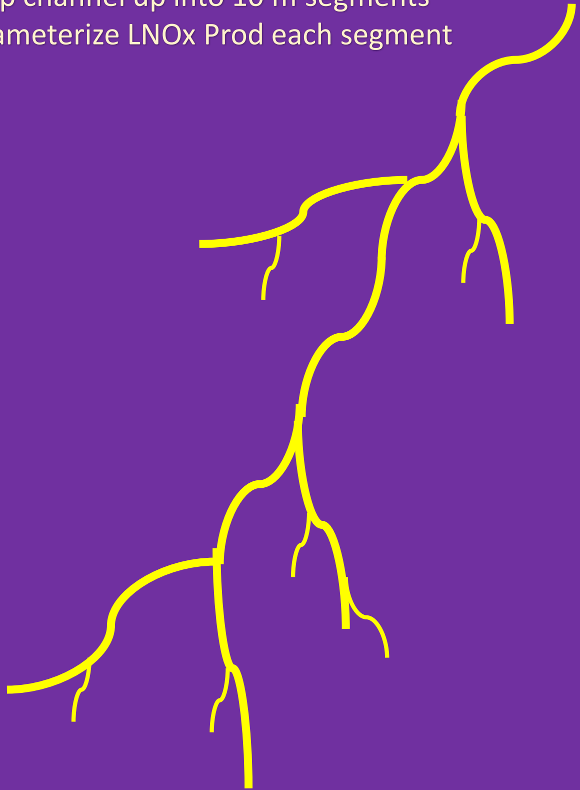
LMA Data

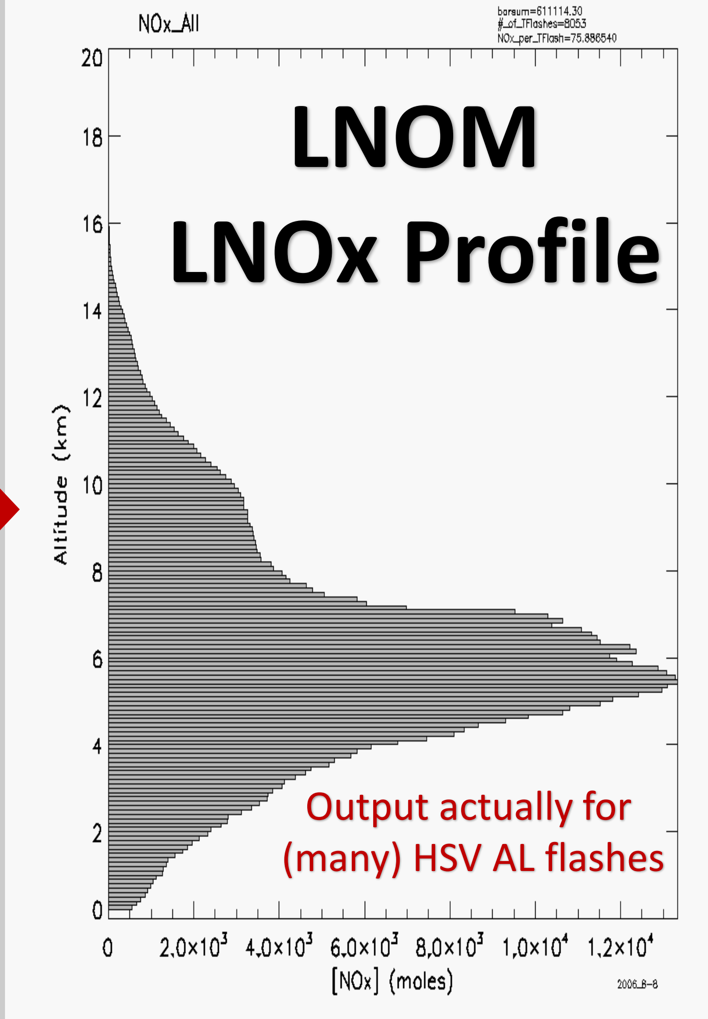


NLDN Data

LNOM
(Lightning Nitrogen Oxides Model)
Analysis Cylinder

- Chop channel up into 10 m segments
- Parameterize LNOx Prod each segment





See: Koshak, W. J., H. S. Peterson, A. P. Biazar, M. Khan, and L. Wang, 2014: The NASA Lightning Nitrogen Oxides Model (LNOM): application to air quality modeling, *Atmos. Res.*, **135-136**, 363-369.

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