Lightning : An Essential Climate Variable

WMO/GCOS Task Team on Lightning Observations For Climate Applications (TT-LOCA) – Final Report

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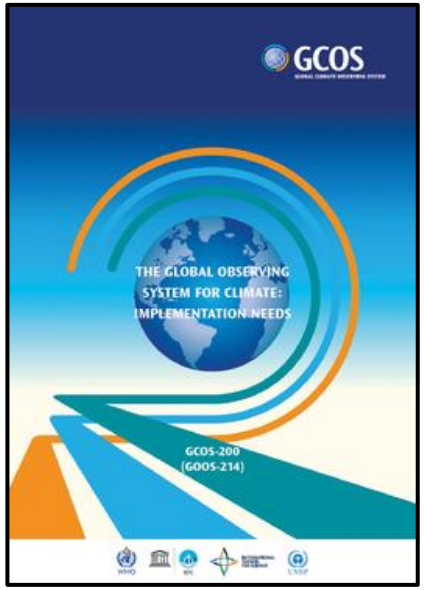

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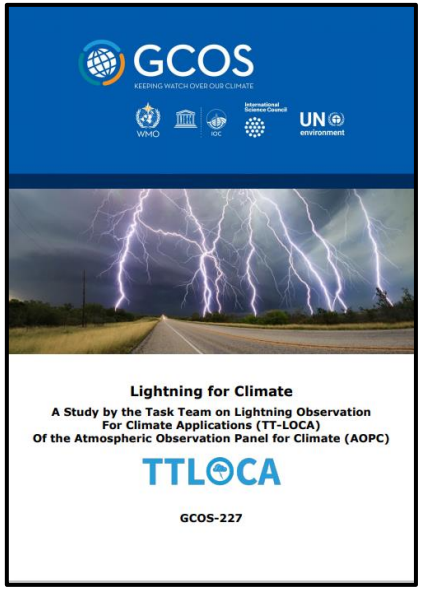
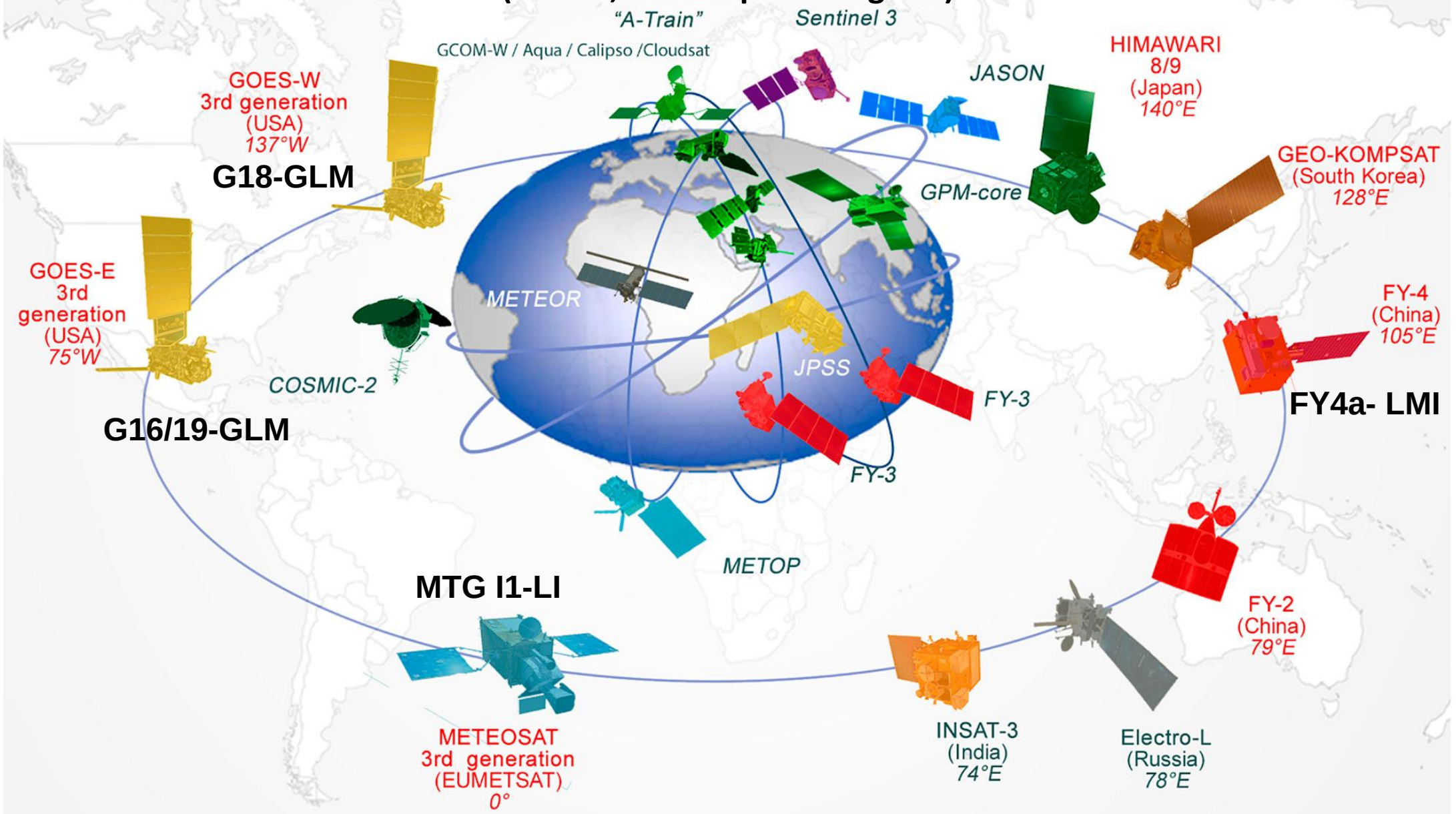


GCOS AOPC29, Asheville NC, 17-20 September 2024

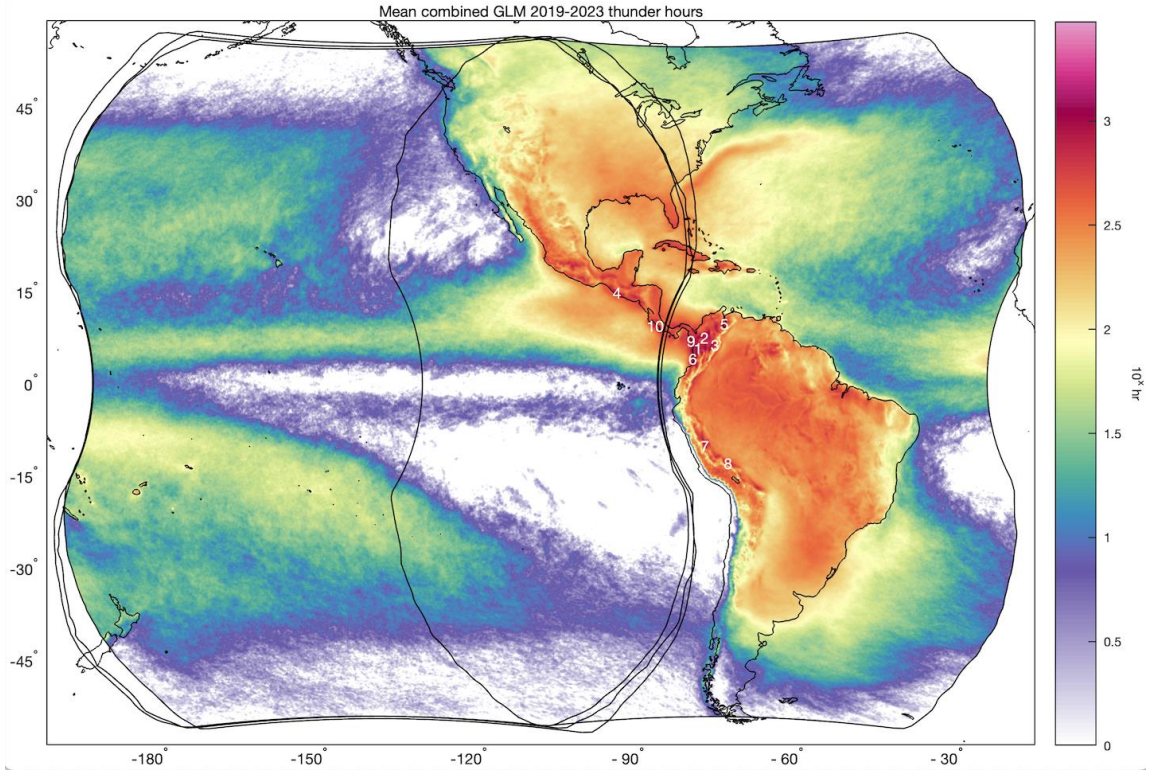
Space-based Component of the Global Observing System

(source, WMO Space Program)

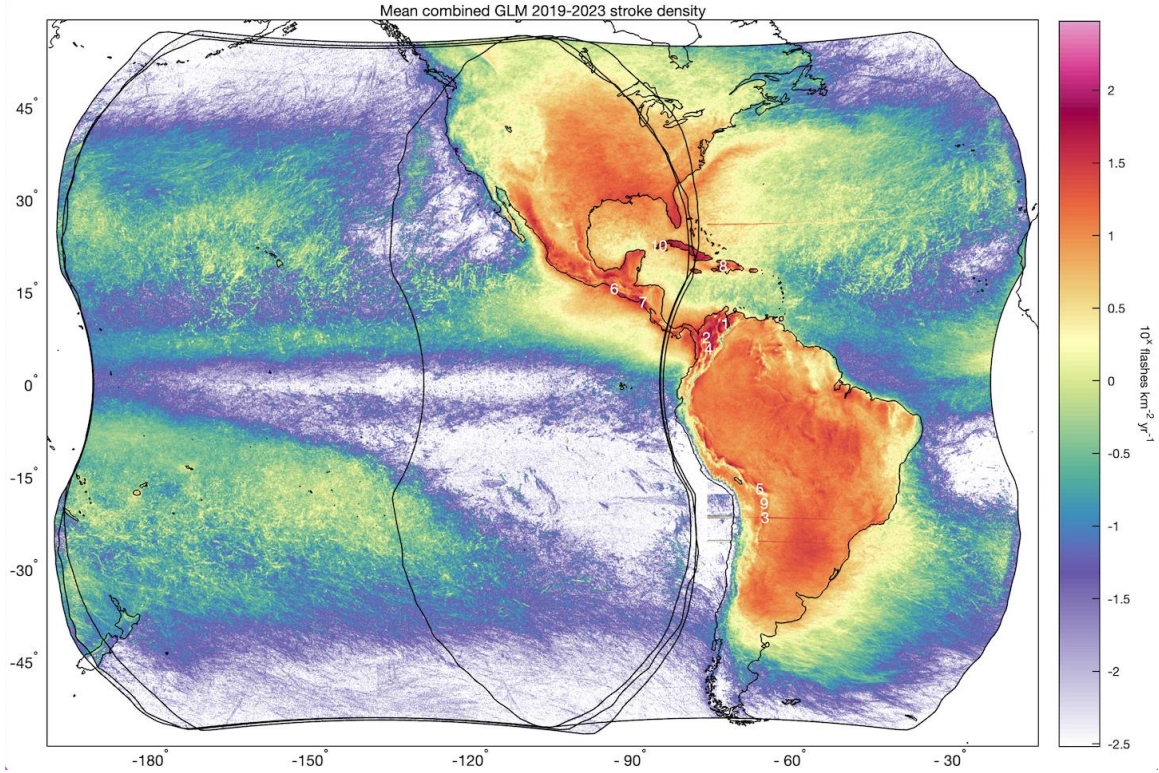


Combined GOES-West and GOES-East GLM

Top ten hotspots in white



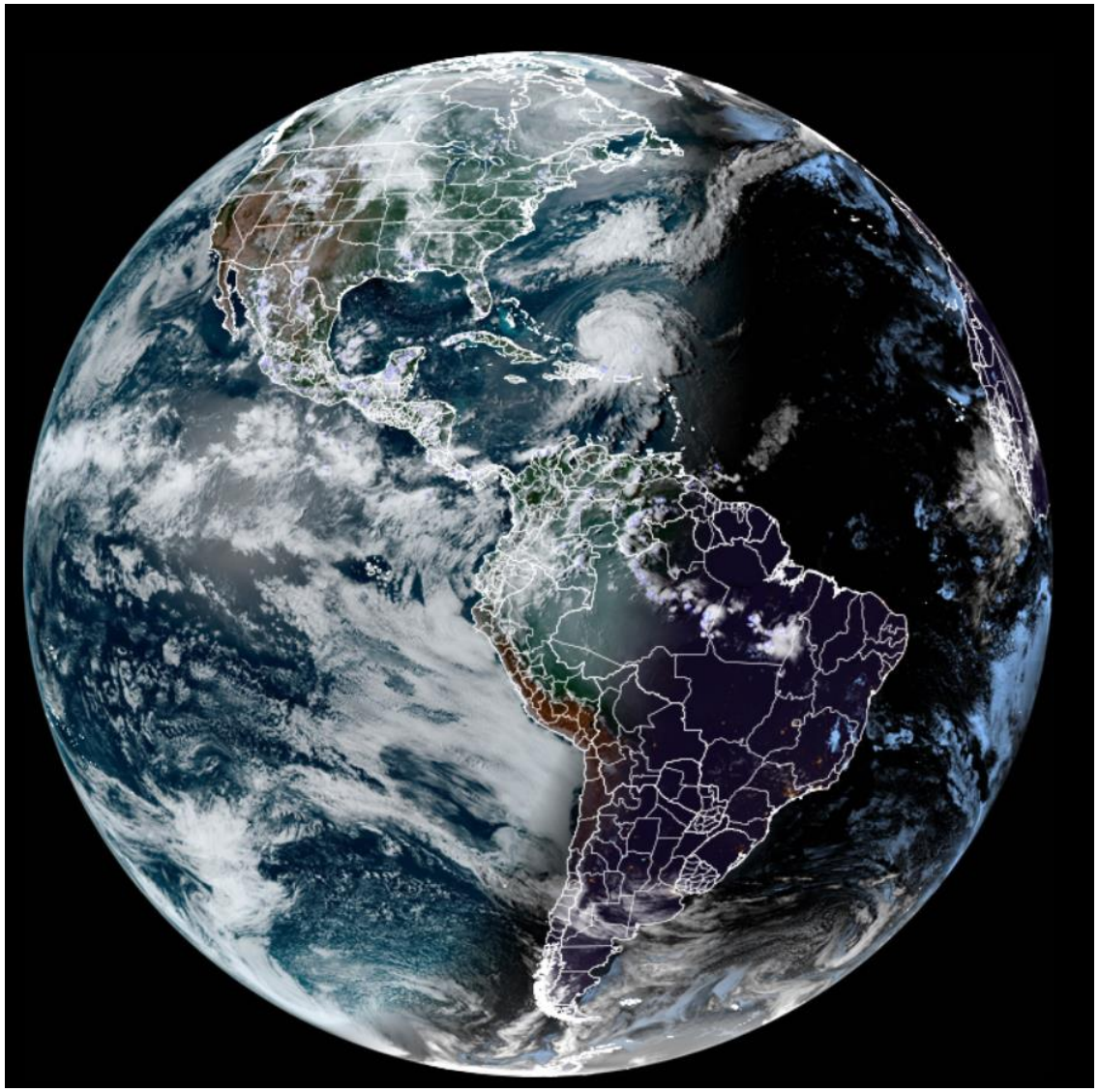
GLM Thunder Hours 2017-2024



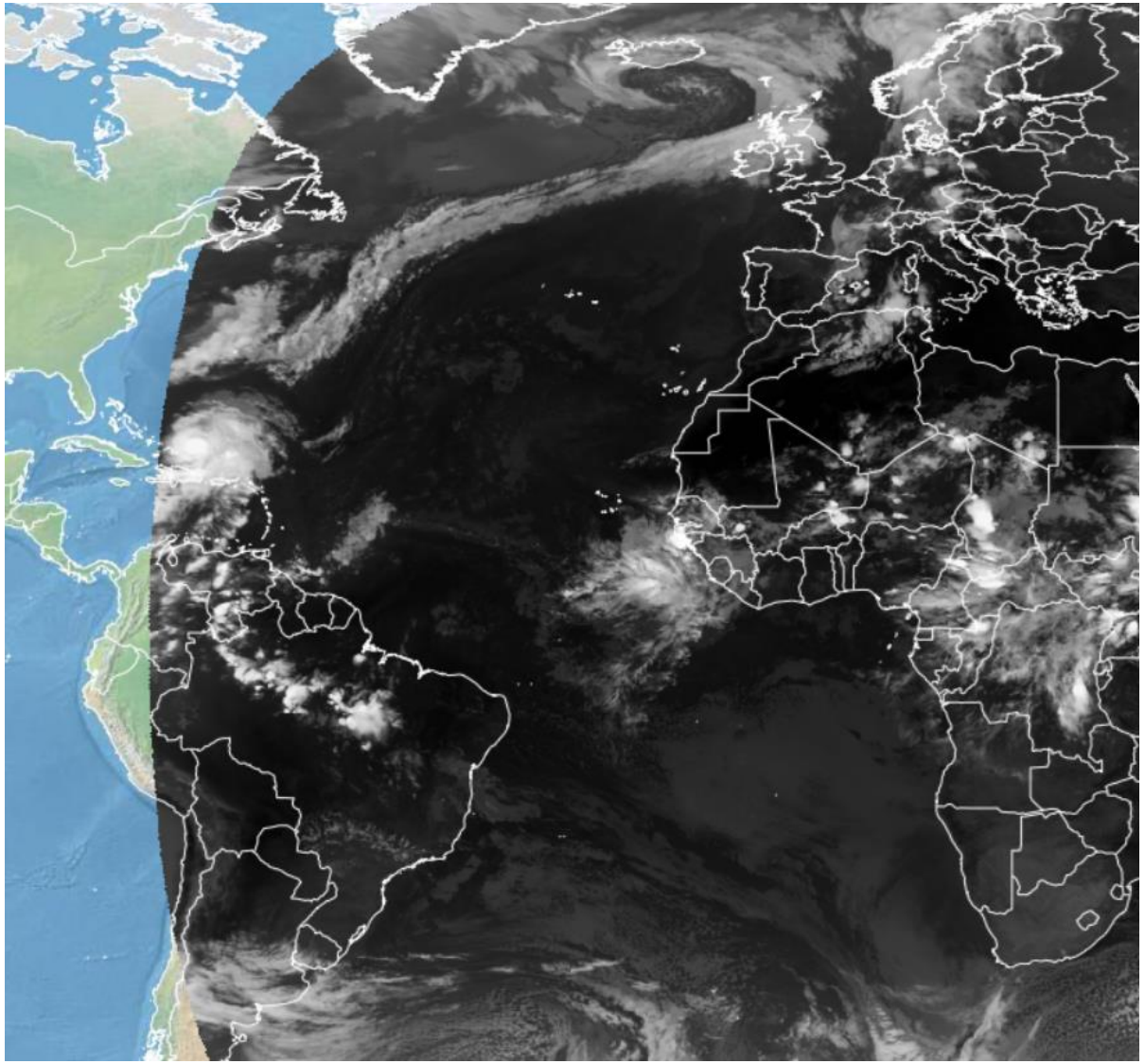
GLM Stroke Density 2017-2024

Source: Katrina Virts, 2024 Lightning Science Meeting, September 24-26, 2024, Huntsville, AL

Geo-Ring - Americas

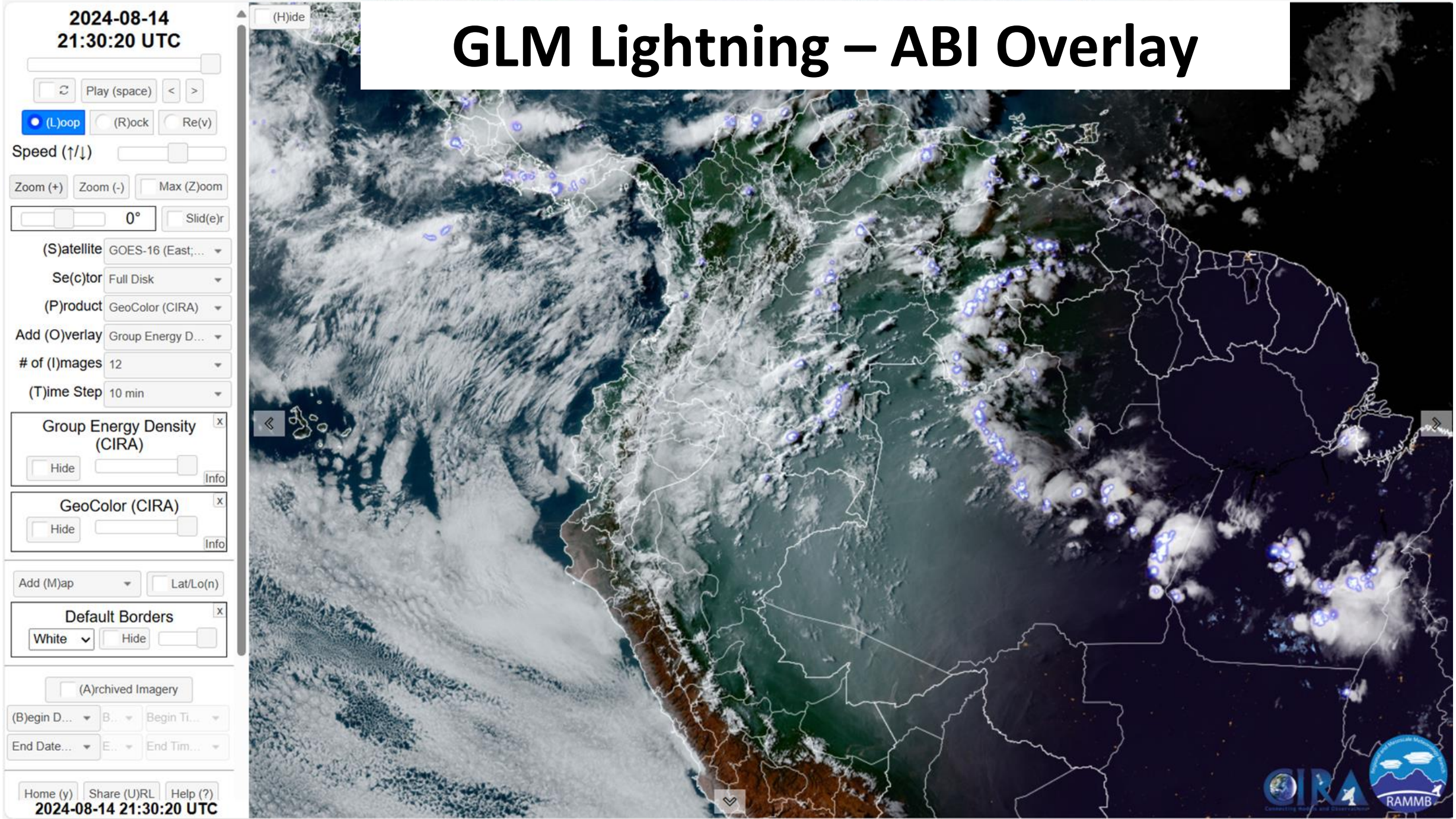


G16 ABI

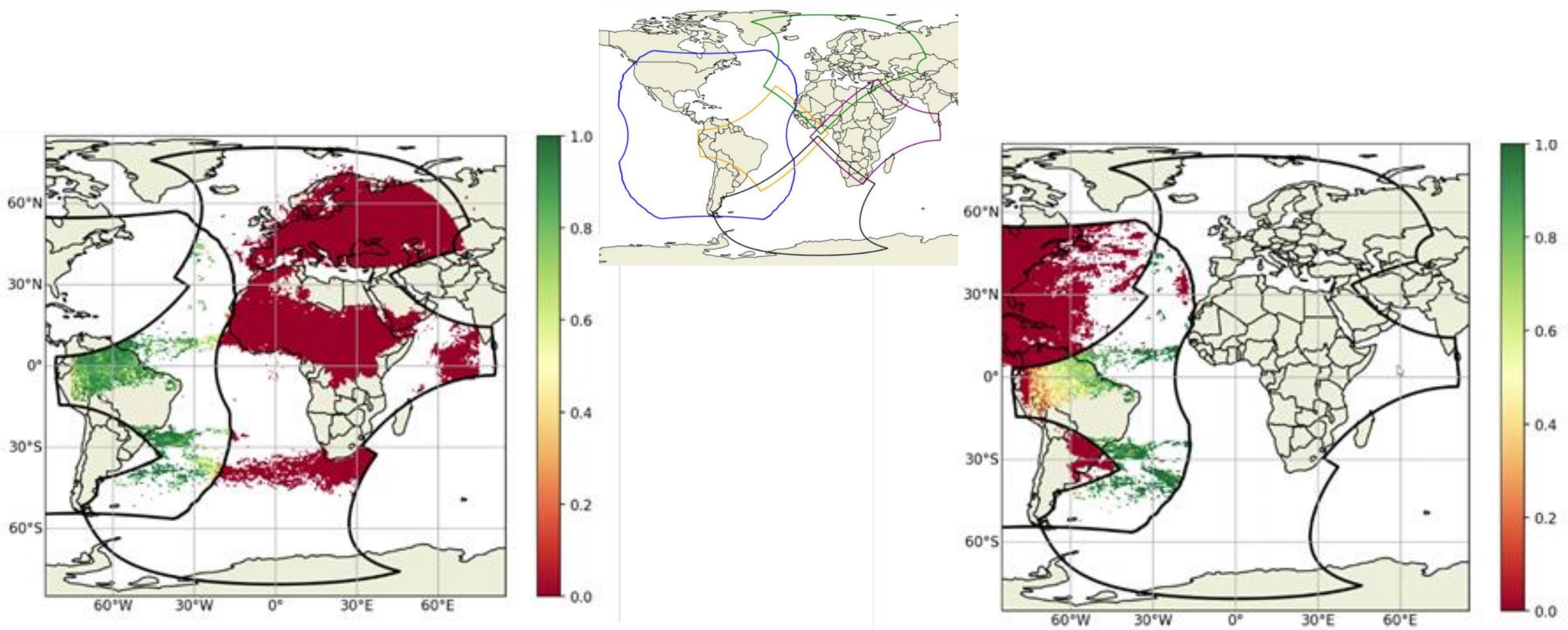


MTG FCI

GLM Lightning – ABI Overlay



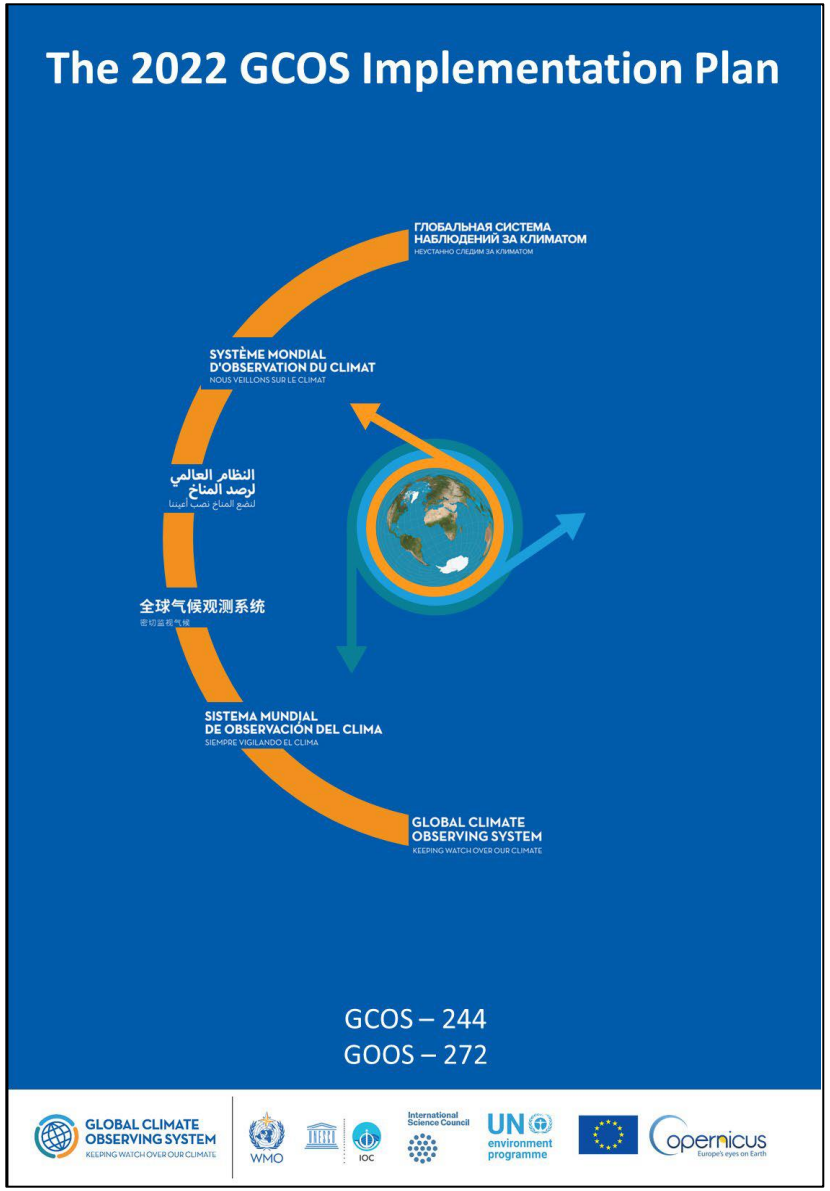
GOES-East GLM Overlap with MTGI1-LI



Source: EUMETSAT, MTG LI on-line short course – September 5, 2024

Lightning Climate Data Requirements

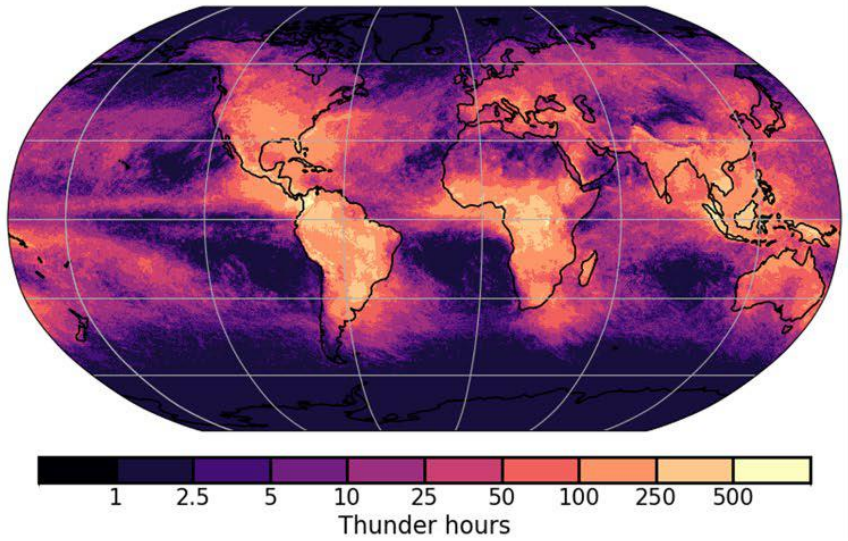
- Total Lightning Stroke Density
- Thunder Hours
  - Consistent, Harmonized Data
- Global 10 km x 10 km (0.1 x 0.1 deg)
- Temporal (Monthly, Daily, Hourly)
- Space-based Optical:
  - NASA TRMM/ISS - LIS
  - NOAA/NASA GOES - GLM
  - CMA FY-4 - LMI
  - EUMETSAT MTG - LI
- Ground-based RF (commercial data):
  - GLD360 (Vaisala)
  - ENTLN (Earth Networks)
  - WWLLN (Univ. Washington)
  - Regional Networks (IC/CG)

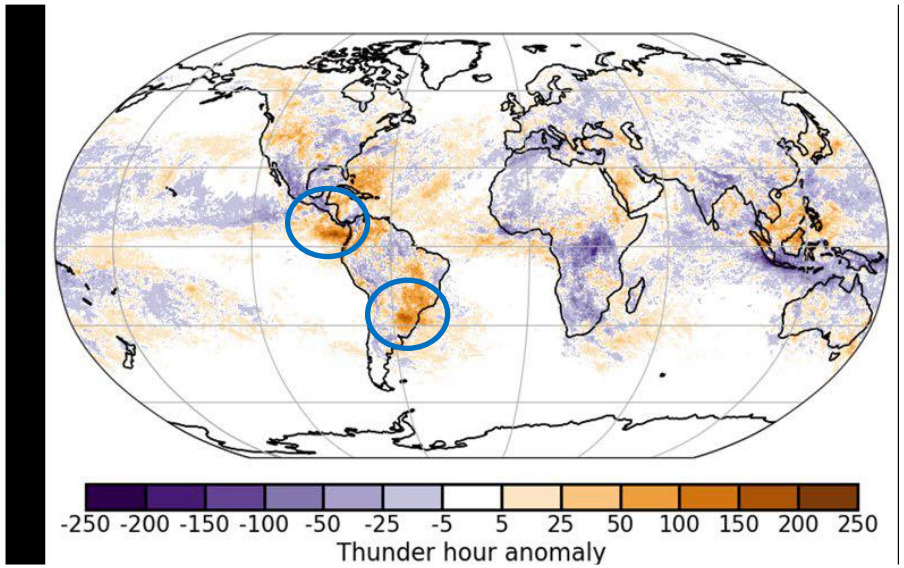


2022 GCOS 5-year Implementation Plan: Remaining and Additional Activities
Presented at AOPC28

- Activity
  - TT-LOCA two-year extension planned principally to establish the stewardship of the Lightning ECV. Naming a liaison to the AOPC for further coordination through 2024 also under consideration to evaluate the space-based and ground-based ECV data sets, reprocessing, and initial results from the MTG-LI.
  - Continue outreach to operators of regional ground-based lightning networks to provide ECV compatible data sets.
  - Drafted a summary report to follow the initial GCOS-227 Report “Lightning for Climate”.
- Plans for ECV Data Stewardship
  - Global VLF operators (GLD360, ENGLN, WWLLN) offered to provide stewardship, maintain and update their ECV product (monthly gridded product, Thunder Hour)
  - **NOAA NCEI** - stewardship of operational and GLM reprocessed data
  - **NASA** – GHRC DAAC stewardship of the OTD/LIS reprocessed data, and Cloud Service landing page (to be developed and coordinated with NCEI) for all Lightning ECV products.

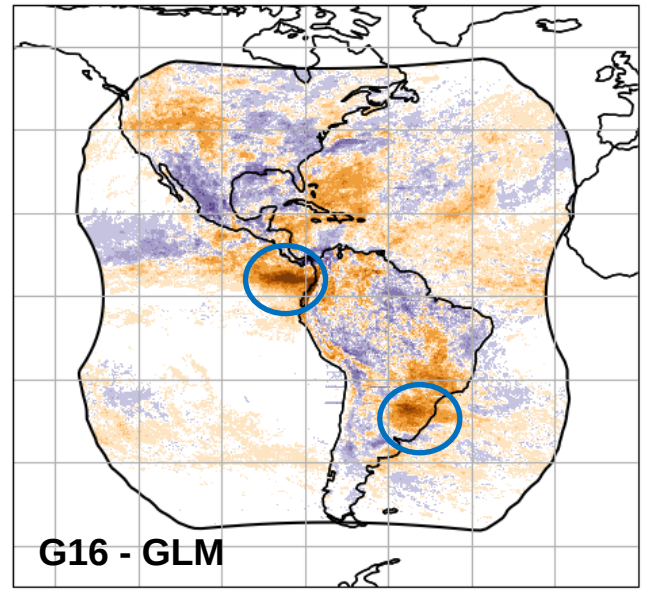
Lightning and El Niño – Thunder Hours





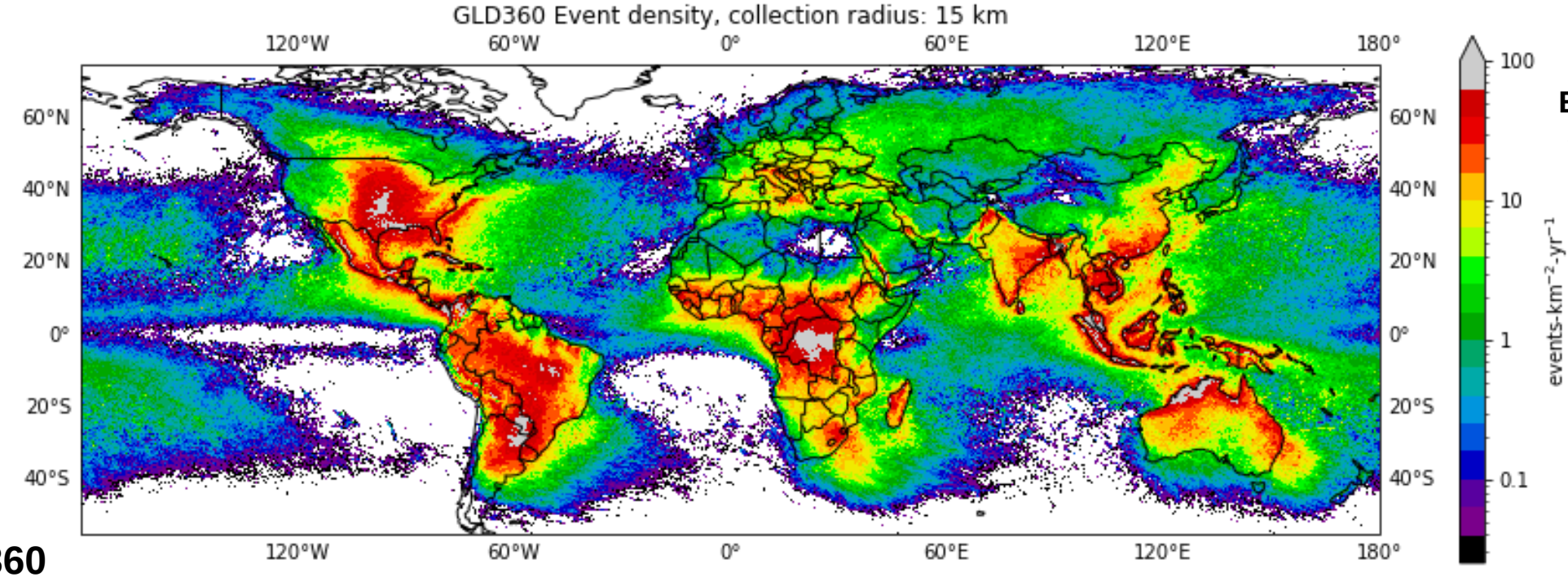
Above, Left - The total number of thunder hours for the year 2023 is averaged from three ground based global lightning detection networks, (Vaisala GLD360, AEM ENTLN and UW WWLLN). Right -The thunder hour anomaly for the year 2023 is calculated from the difference between the thunder hours in 2023 and the five-year average from 2018-2022. The enhancement of thunder hours on the west coast of Colombia is attributed to increased convection arising from the sea surface temperature anomaly El Niño.

Füllekrug et al., 2024: **Special Supplement to the** *Bulletin of the American Meteorological Society* **Vol. 105 No. 8, August 2024**

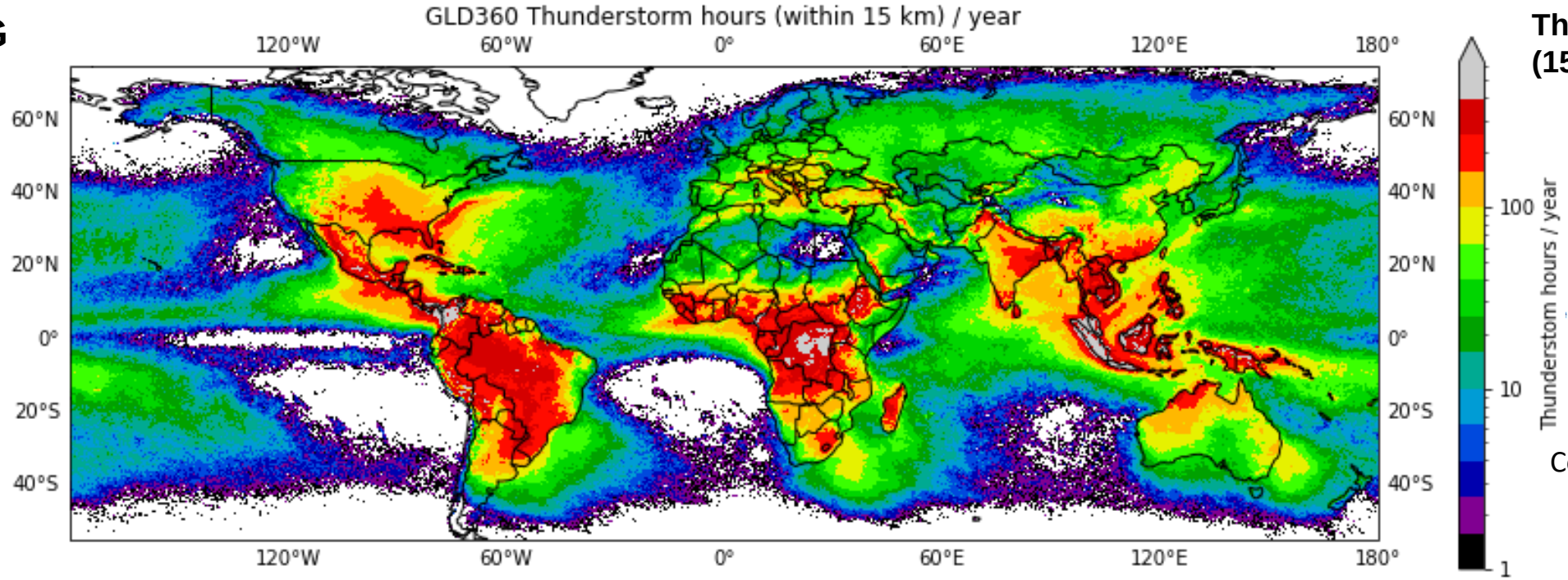


The thunder hour anomaly for the year 2023 calculated from NOAA's Geostationary Lightning Mapper (GLM) on the Geostationary Operational Environmental Satellite GOES-16 compares well to the 2023 anomalies calculated from ground-based lightning detection networks. The two enhancements of thunder hours south of central America are attributed to the El Niño phenomenon.

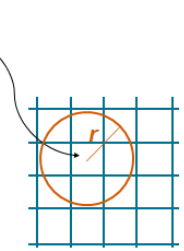
GLD360
IC+CG



Event Density 2015-2019
(0.1 deg grid)



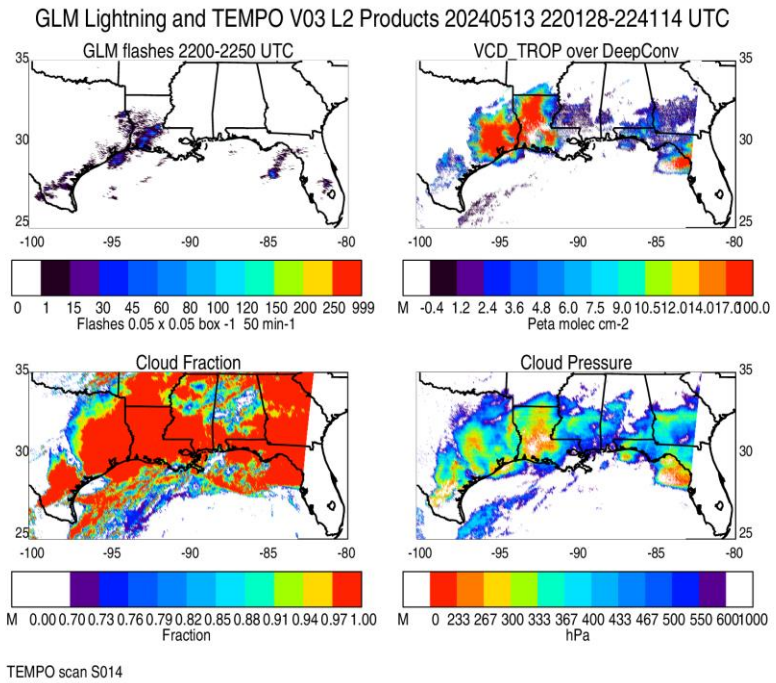
Thunder Hours 2015-2019
(15 km radius)

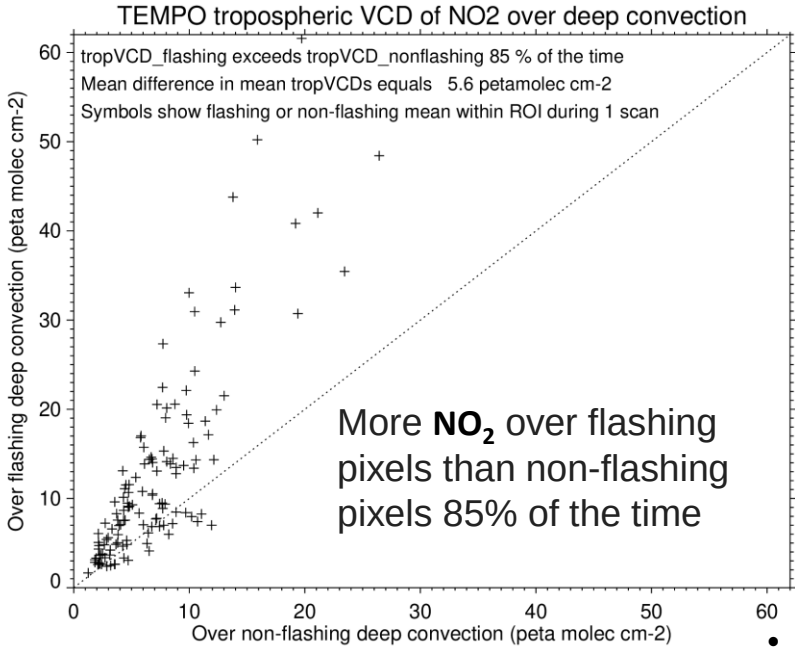


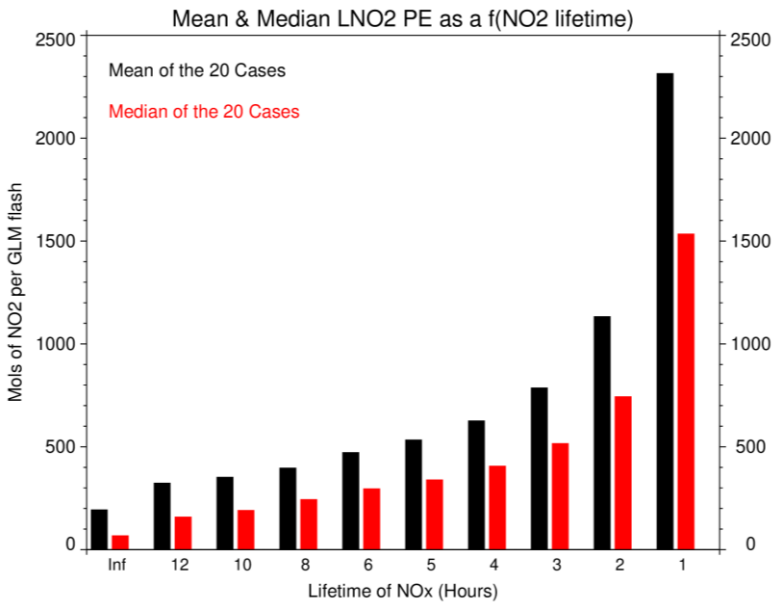
Courtesy of Ryan Said, Vaisala

Geostationary Lightning and Atmospheric Composition Observations

- **NO_x production by lightning (LNO_x) estimated using NO_2 from TEMPO and flashes from GOES-16/18 GLM.**
- **LNO_x is injected primarily in the middle and upper troposphere where it leads to enhanced total reactive N, OH, and O_3 and decreased CH_4. Longwave radiation absorption by O_3 is increased and by CH_4 is decreased.**
- **Resolution of NO_2 product is as fine as 2.1 km n-s by 4.4 km e-w. Daylight scans performed every 40 to 60 mins.**





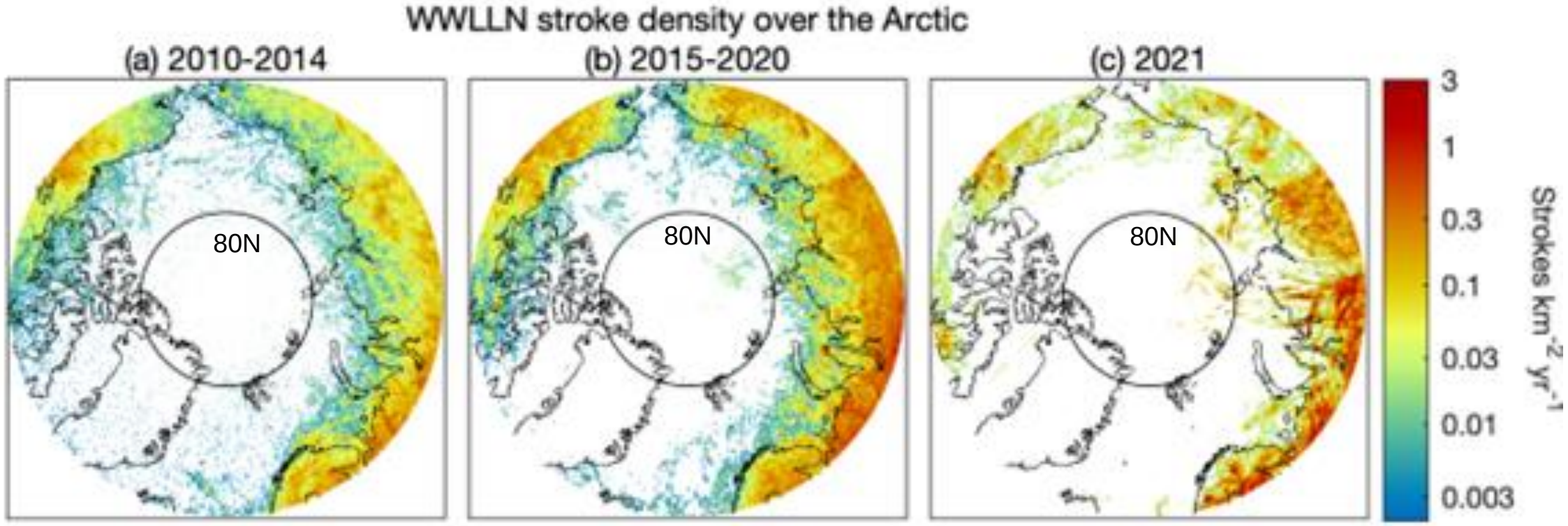


Differences in tropospheric vertical columns of NO_2 (VCD_TROP) between flashing pixels (with flashes in last 3-hrs) & non-flashing deep convective pixels (cloud fraction > 0.97 and pressure < 500 hPa) used to estimate moles of lightning-NO_2.
Note: NO_2 retrievals unavailable over convection when scene is too bright (mid-day).

- **Moles of NO_x produced per flash (LNO_x PE) is function of assumed NO_x lifetime. Lifetimes of 2 – 5 hours provide the most consistent estimates of LNO_x PE across TEMPO scans.**
- **Synergy of TEMPO and GLM observations to be continued with GeoXO and ACX**

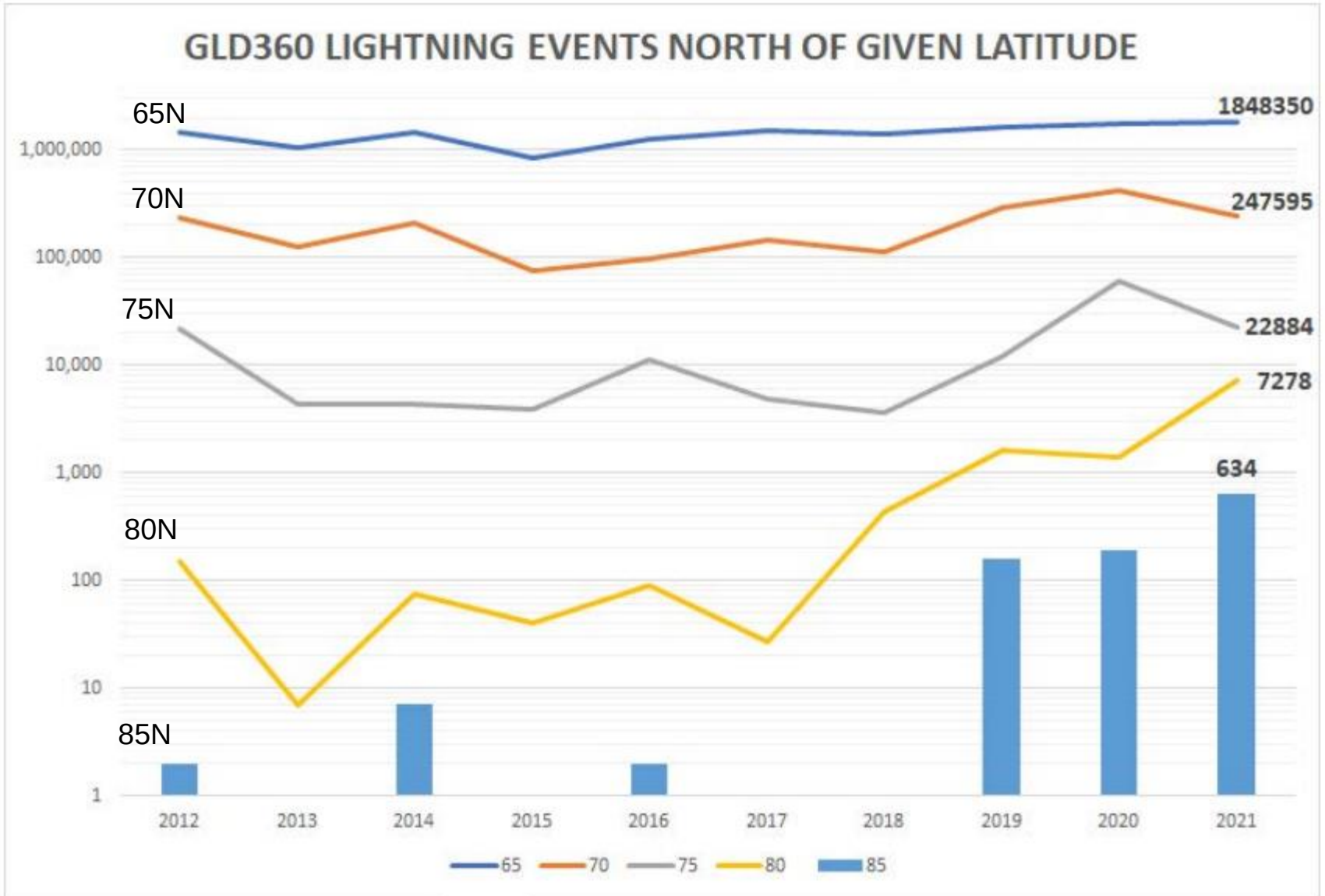
Source: Dale Allen and Ken Pickering – University of Maryland

Attribution : How is the increase in high latitude lightning linked to a warming Arctic?



Arctic lightning densities recorded by the World-Wide Lightning Location Network (WWLLN) and averaged over the years 2010-2014, 2015-2020, and 2021. The lightning flash densities increased during 2015-2020 when compared to 2010-2014. In 2021, northern Europe and much of northern Russia continued to experience higher overall lightning densities. Eastern Russia and northern North America generally experienced less lightning than the previous 2015-2020 period.

BAMS Special Supplement Issue on Climate, 2022

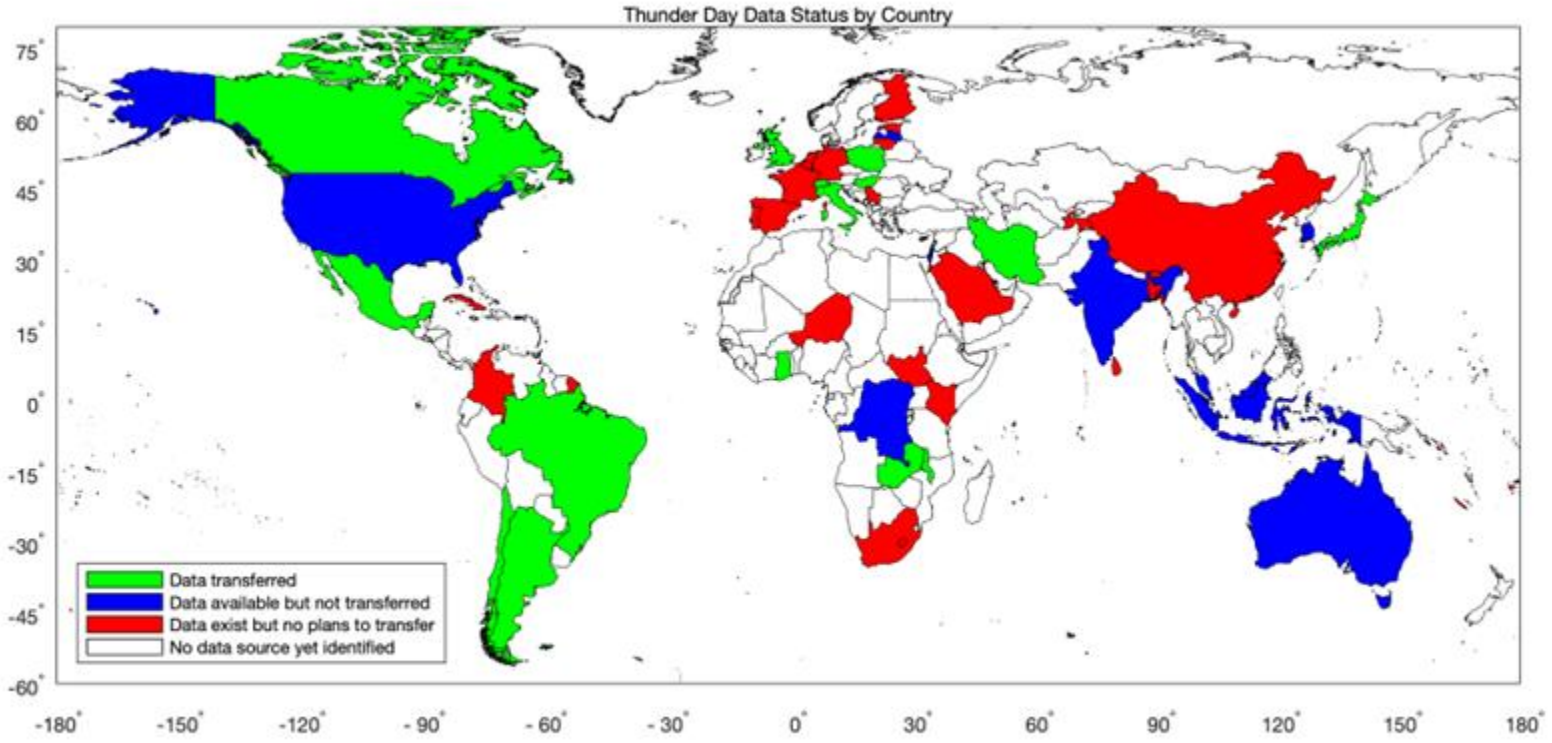


Courtesy Vaisala, Inc.

Thunder Day Records

Status:
TTLOCA requested assistance from WMO/GCOS in obtaining the missing Thunder Day Records

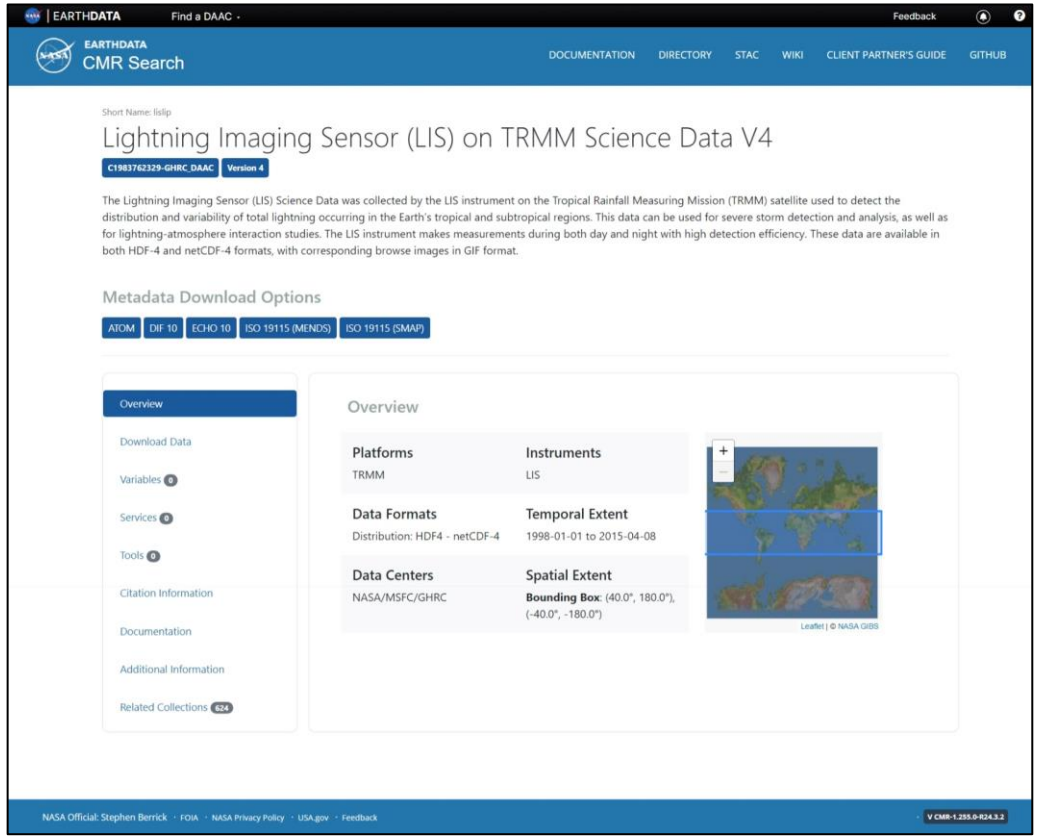
A methodology developed by Lavigne and Liu, JGR 2019) can be used to analyze the extended data base.



A Look Ahead

Data Stewardship at NASA's Earthdata Portal

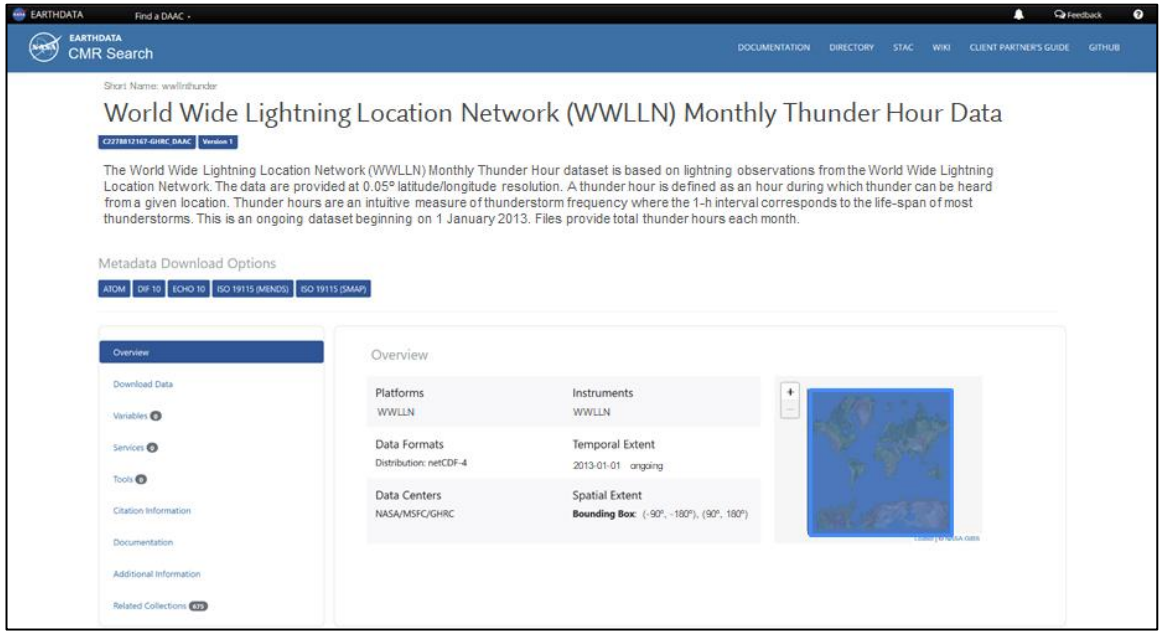
[CMR Search - Landing Pages for GHRC_DAAC EOSDIS Collections (nasa.gov)]



NASA Earth Science Data portal web page for LIS monthly data sets.

Some of the advantages of this dataset being accepted to a NASA DAAC are

- Cloud-based archive to enable easier access, processing in the cloud, and access to other archived lightning data
- Long-term storage: This is more than a web page on a single server. The DAACs provide free access for years to come, complete with redundant backups
- GHRC DAAC, through a user working group is developing visualization and analysis tools to support science use



NASA Earth Science Data portal web page for WWLLN monthly data sets.

Geostationary Extended Observations

GXI
Vis/IR Imager

- Hurricane location / track
- Severe storms, rain, wind, hail
- Atmospheric rivers, flooding
- Winter storms, ice cover
- Wildfire, smoke, volcanic ash
- Methane plume monitoring
- Aviation hazards, turbulence

GXS
Hyperspectral IR Sounder

- Numerical weather prediction
- Hurricane track / intensity
- Now-casting
- Warn-on-Forecast
- Air quality monitoring

ACX
Atmospheric Composition Instrument

- Air quality forecasting
- Air quality monitoring
- Airborne hazards
- Emissions monitoring

LMX
Lightning Mapper

- Thunderstorm / tornado warning
- Wildfire ignitions
- Precipitation forecasts
- Tropical storm diagnosis

OCX
Ocean Color Instrument

- Harmful algal blooms
- Water quality
- Oil spill tracking
- Plankton classification
- Refined fisheries yield
- Habitat / species protection
- Naval forecasting

Note:
OCX represented by GLIMR
LMX represented by GLM
ACX represented by TEMPO

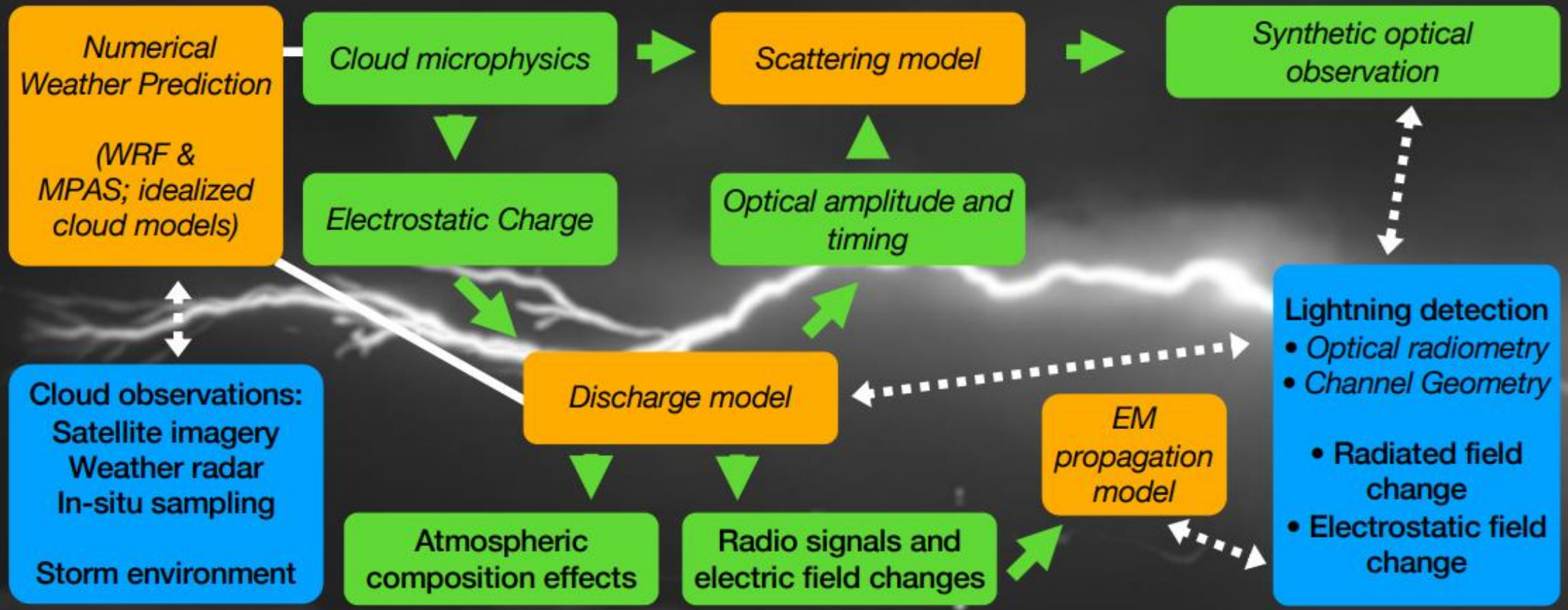
Observables ⟷ comparison | *Major model component* | *Physical entity*

Given a mature forward model, observations can also be assimilated into NWP systems to adjust model state

Science Workshops:
April 1-3, 2024, Albuquerque, NM
April 1-3, 2025, Texas Tech, Lubbock, TX

DRAFT Lightning modeling framework

Italics indicate first steps using available or near-term tools and observations



"Coupled meteorological and optical modeling of lightning", presented to SNL by Dr. Eric Bruning, Professor and Dr. Kelcy Brunner, Research Scientist, Texas Tech University Lightning Meteorology Group, 17 May 2023

Summary

- **Lightning is a global Natural Hazard** of great importance and interest

- **Exemplary lightning datasets –** evaluating candidate data sets (satellite – Ground-Based RF)
  - Lightning Density
  - Thunder Hour (WWLLN, ENGLN, GLD360, GLM)
  - Gridded at 0.1 x 0.1 deg (GLD360, WWLLN, GLM, MTG-LI, Regional Networks)
  - Developing input to the GCOS 5 – year Implementation Plan
  - Archive and Stewardship in the cloud supported by the NASA GHRC Hydrometeorology DAAC (Distributed Active Archive Center)
- **How might a lightning ECV be associated with other variables**, such as clouds, precipitation, composition, NOx, and surface observations (e.g., temperature, severe weather reports), ENSO, MJO, Upper-Level humidity.

- **Raise lightning safety awareness** – collaborate with WHO, WMO Disaster Risk Reduction (Natural Hazards) Programme

Acknowledgements

- Katrina Virts – Univ. of Alabama in Huntsville (UAH)
- Geoffrey Stano – UAH
- Martin Füllekrug – Univ. of Bath, UK