Lightning : An Essential Climate Variable

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

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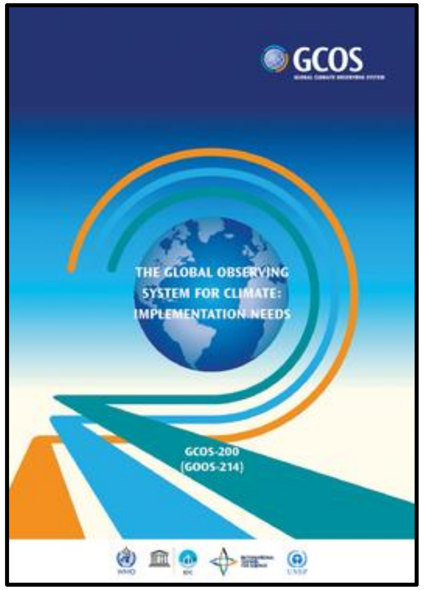

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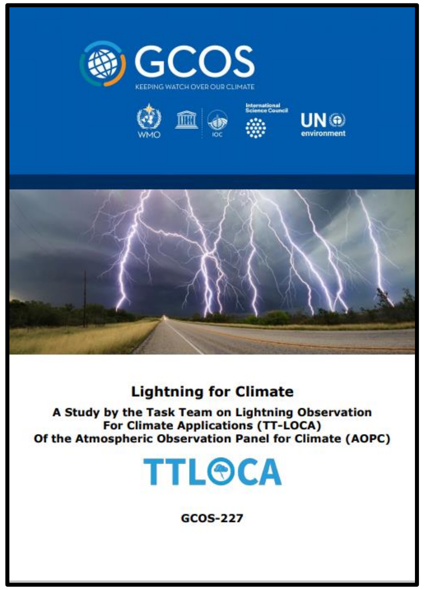
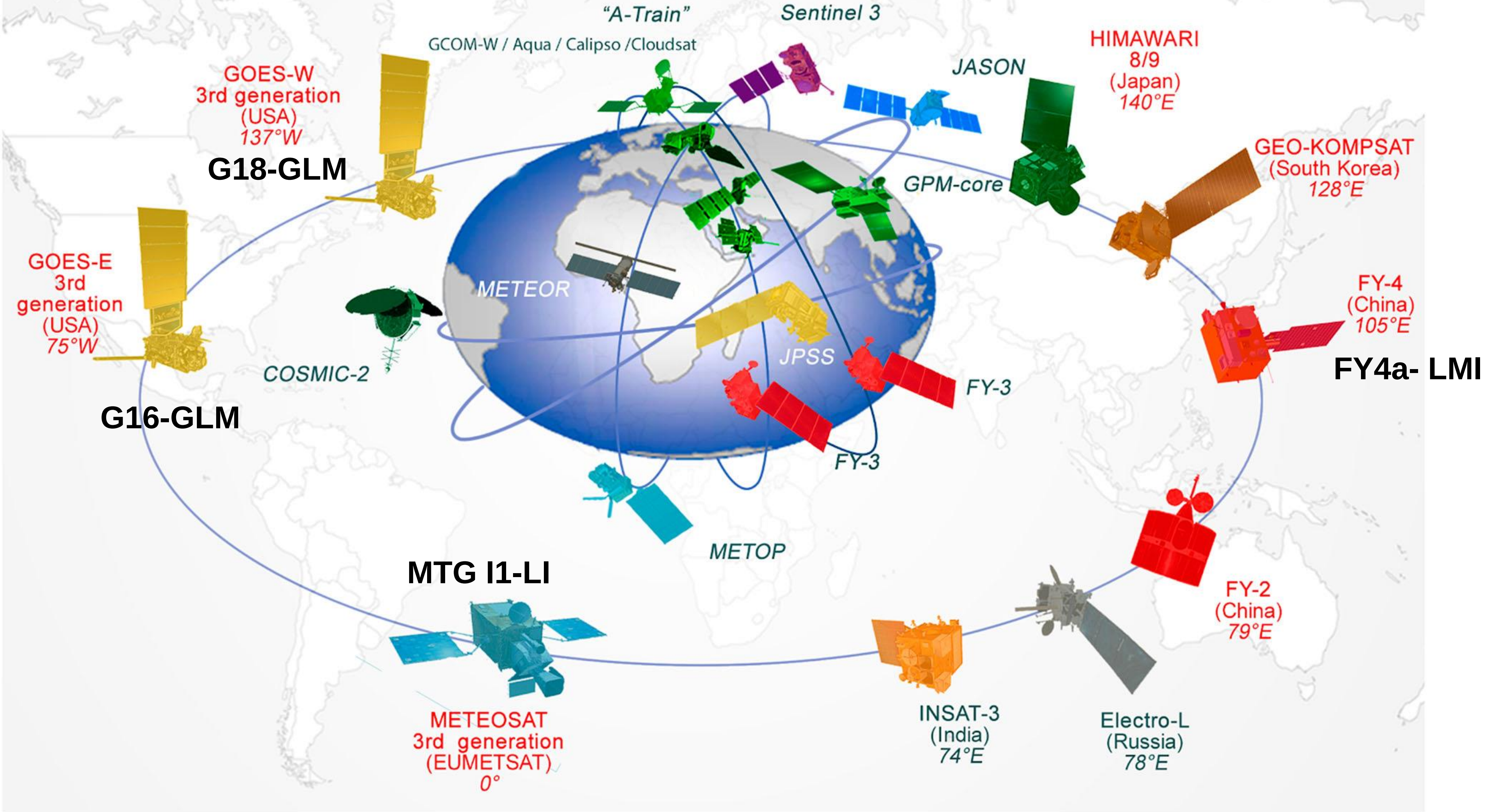
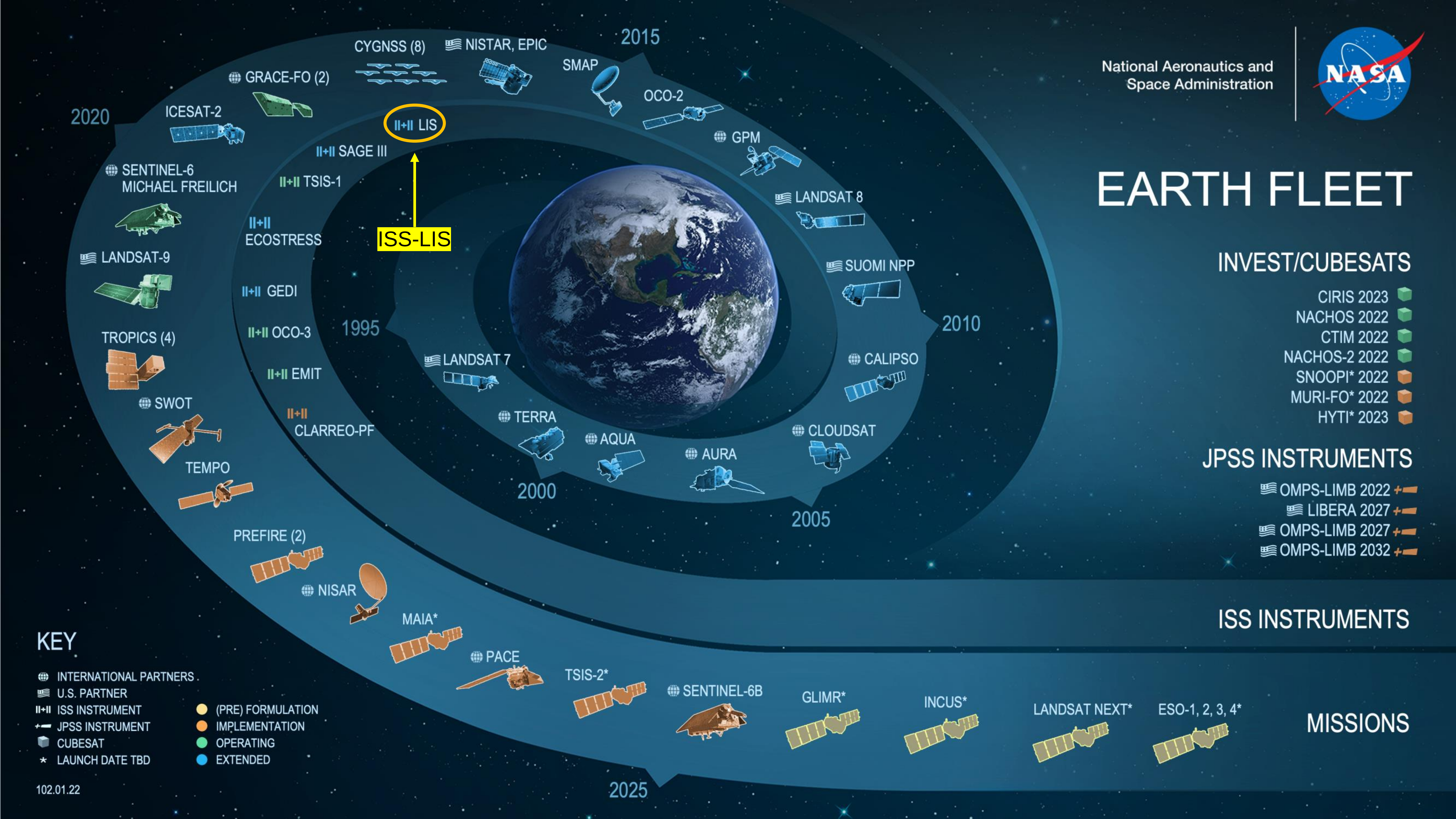


GCOS AOPC28, 26 June 2023

Space-based Component of the Global Observing System

(source, WMO Space Program)




National Aeronautics and Space Administration
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ESO-1, 2, 3, 4*
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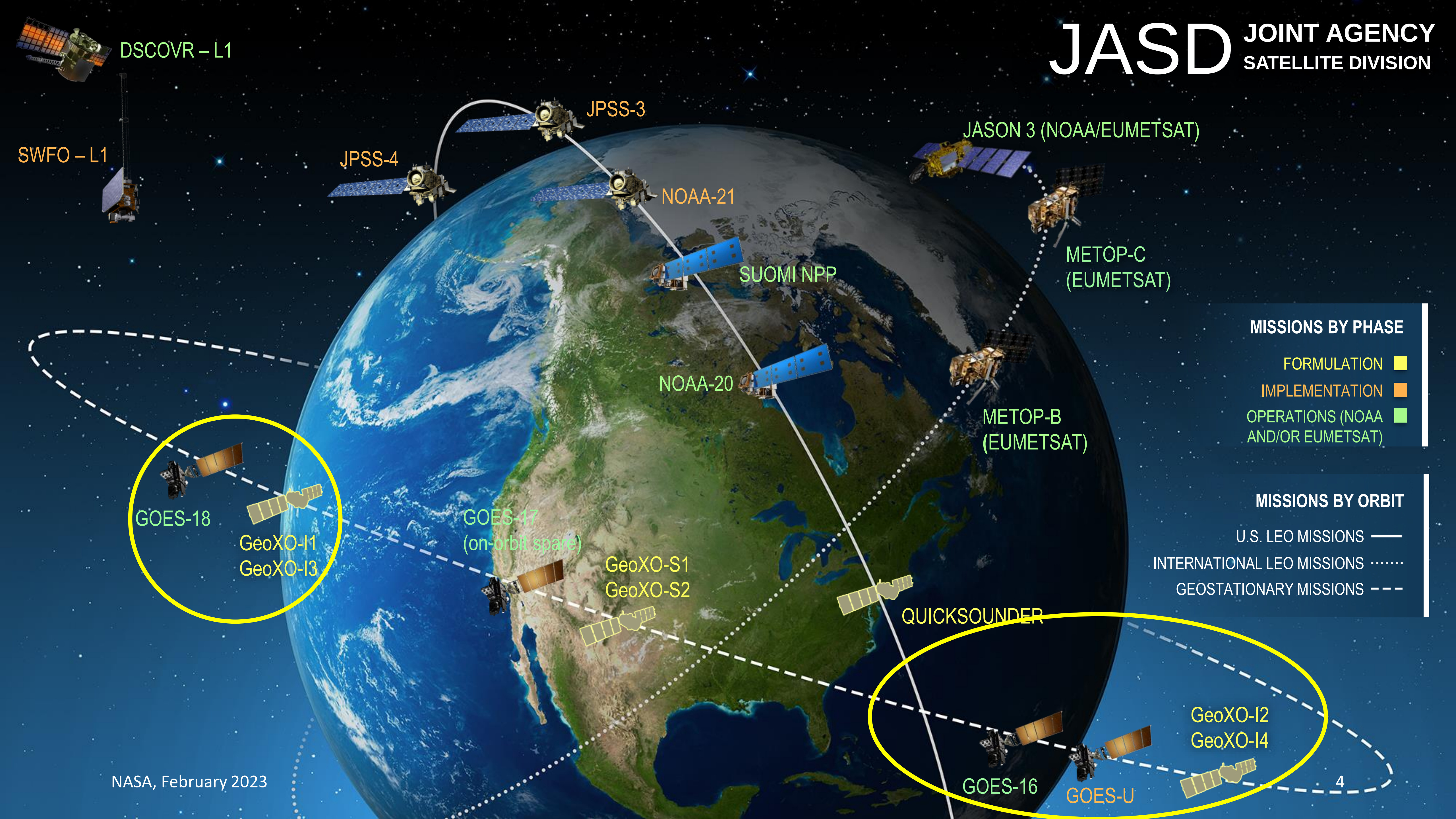
JASD
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NOAA-21
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GEOSTATIONARY MISSIONS
GOES-18
GeoXO-I1
GeoXO-I3
GOES-17
(on-orbit spare)
GeoXO-S1
GeoXO-S2
QUICKSOUNDER
GeoXO-I2
GeoXO-I4
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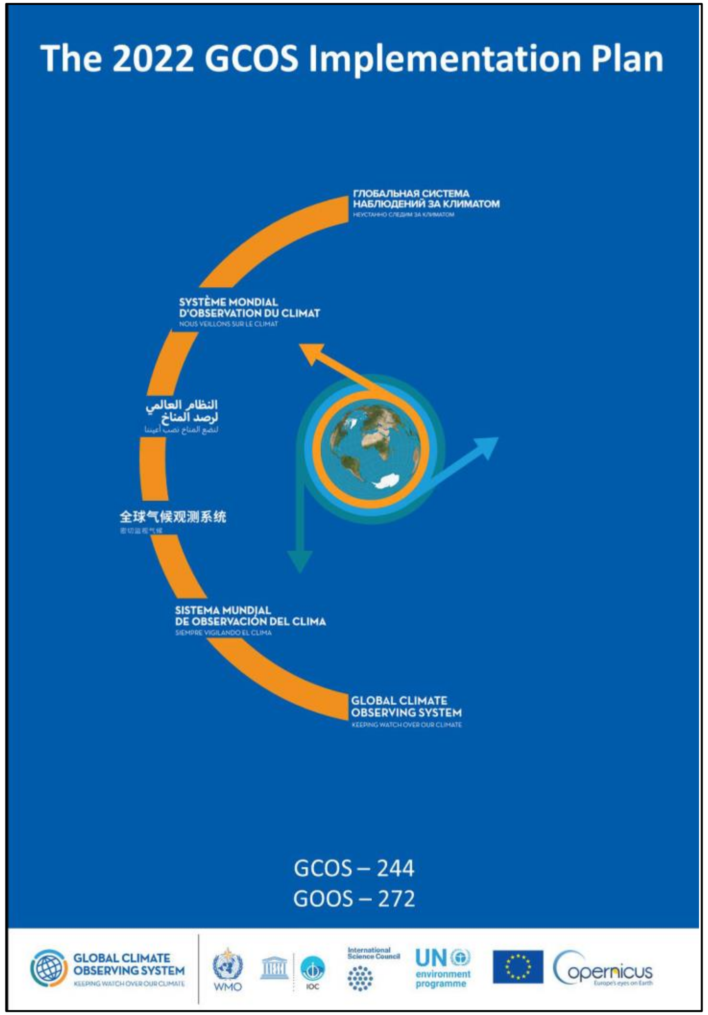
2022 GCOS AOPC IP – Lightning Actions Accomplishments, Status, and Plans

Lightning

Thunder Days

Ionospheric Potential- GRUAN



BAMS SotC, August 31, 2022

Sidebar 2.1: **Lightning**—M. FÜLLEKRUG, E. WILLIAMS, C. PRICE, S. GOODMAN, R. HOLZWORTH, K. VIRTS, AND D. BUECHLER

The World Meteorological Organization (WMO) recently declared lightning flashes to be an essential climate variable (ECV), based on a recommendation by the Task Team on Lightning Observation for Climate Applications (TT-LOCA) as part of the Atmospheric Observation Panel for Climate (AOPC) of the WMO and the Global Climate Observing System (GCOS; Aich et al. 2018; WMO 2019a). This endorsement reinforces the WMO Integrated Global Observing System (WIGOS) Vision 2040 (WMO 2019b) toward the operational observation of lightning by space agencies during the coming decades.

Lightning flashes are generated by thunderstorms, which develop when hot and humid air destabilizes the atmosphere and enables deep convection. As a result, the lightning ECV is grouped with other ECVs describing the atmosphere (Bojinski et al. 2014) which are closely related to thunderstorm development, such as the Earth radiation budget, upper-air temperature, water vapor, wind speed, and cloud properties (see sections 2f1, 2b1, 2b5, 2d2, 2e2, and 2d6). The lightning ECV is also related to ECVs that impact atmospheric composition, such as lightning NOx and cloud condensation nuclei (see sections 2g3 and 2g6).

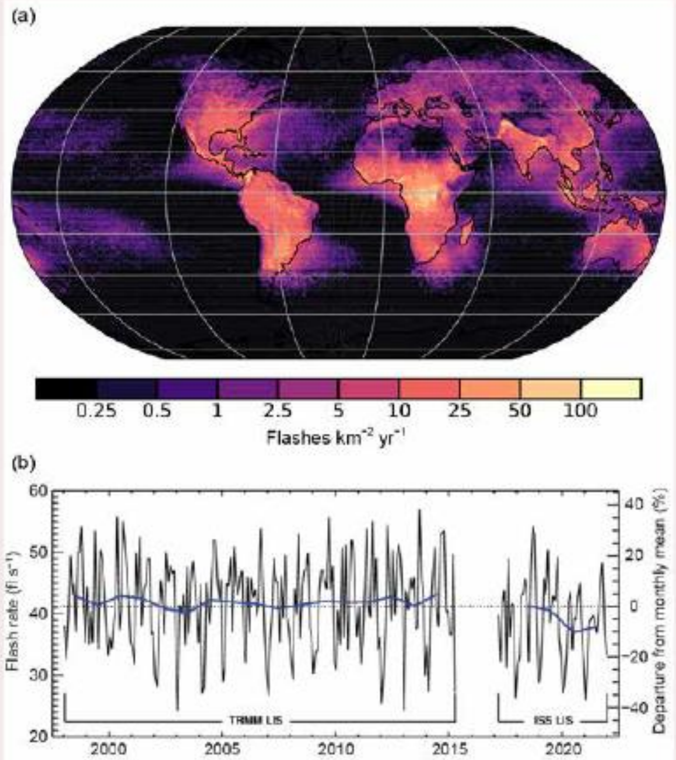


Fig. SB2.1. Lightning observations from space. (a) Global distribution of lightning flash rate density (fl km^{-2} yr^{-1}) for the period of record 1995–2021 from NASA's low earth orbit lightning imagers OTD (Optical Transient Detector, May 1995–Apr 2000), TRMM LIS (Lightning Imaging Sensor, Jan 1998–Dec 2014) and ISS LIS (Feb 2017–Dec 2021). Global lightning is dominant over the continental tropical belt. (b) Monthly (solid black) and annual (blue) mean lightning flash rates (fl s^{-1}) observed by the TRMM and ISS LIS instruments within the ±38° latitudinal coverage of the TRMM orbit. The black dotted line is the combined mean monthly global flash rate (41.2 fl s^{-1}). The mean monthly flash rate varies from ~24 to 57 fl s^{-1}. The seasonal variations are due to the annual cycle of lightning activity linked to the larger land area of the Northern Hemisphere. (Source: Courtesy of the NASA Lightning Imaging Sensor Science Team.)

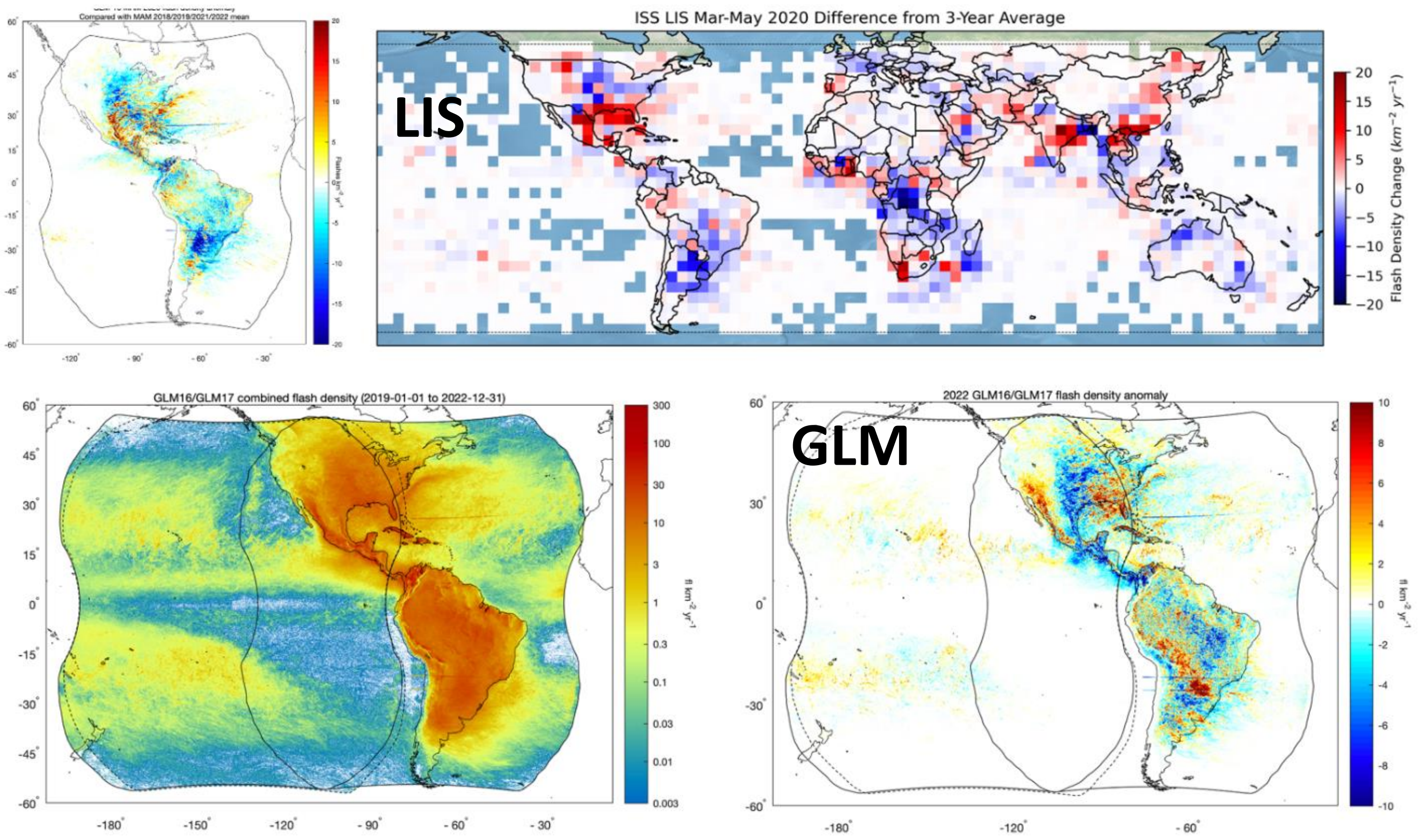
Lightning is a natural hazard associated with the severe weather impacts of thunderstorms including high wind speeds with falling trees and branches, intense precipitation causing flooding, large hail affecting transport vehicles and crops, and cloud-to-ground lightning which can lead to casualties, ignite wildland fires, and cause significant damage to infrastructure, such as power lines (Cooper and Holle 2019; Holle 2016). Lightning has significant societal implications for public safety (Holle et al. 1999), power distribution (Piantini 2020), aviation (Ryley et al. 2020), and wildfires (Holzworth et al. 2021). Wildfires can increase convective instability for pyrocumulus to develop (Rudlosky et al. 2020; Liu et al. 2021; Augustine et al. 2021). Lightning is

Lightning Climate Data Requirements

- **Total Lightning Stroke Density**
  - **Consistent, Harmonized Data**
- **Global 10 km x 10 km (0.1 x 0.1 deg)**
- **Temporal (Monthly, Daily, Hourly)**

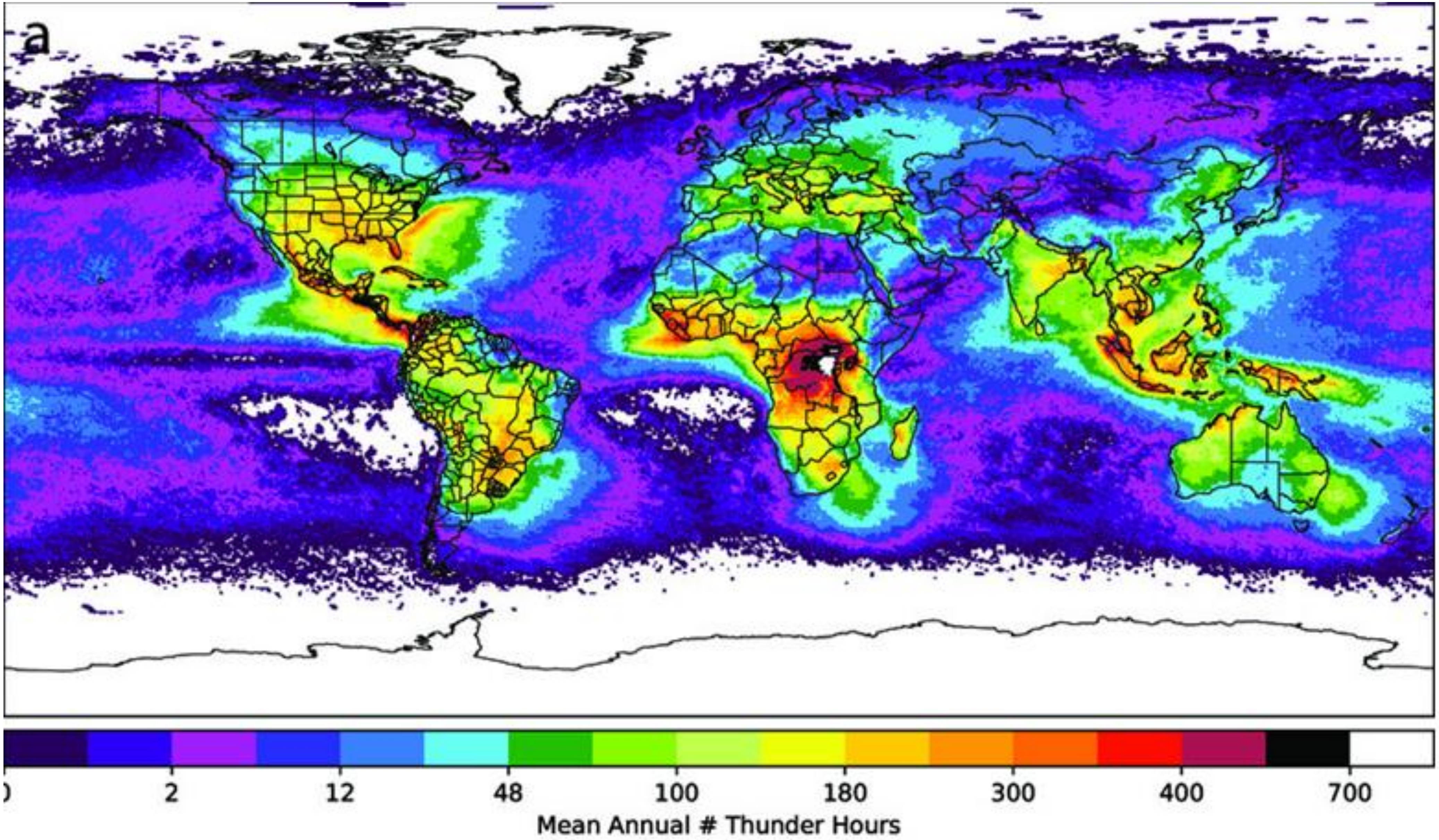
- **Space-based Optical:**
  - **NASA TRMM/ISS - LIS**
  - **NOAA/NASA GOES - GLM**
  - **CMA FY-4 - LMI**
  - **EUMETSAT MTG - LI**
- **Ground-based RF (commercial data):**
  - **GLD360 (Vaisala)**
  - **ENTLN (Earth Networks)**
  - **WWLLN (Univ. Washington)**
  - **Regional Networks (IC/CG)**

Space-based: Total Lightning Flash Density



Top) Lightning Imaging Sensor (LIS) seasonal lightning density anomalies for March-May 2020; Bottom) Combined G16 and G17 GLM flash density anomaly for 2022 that are calculated relative to the 2019-2021 mean.

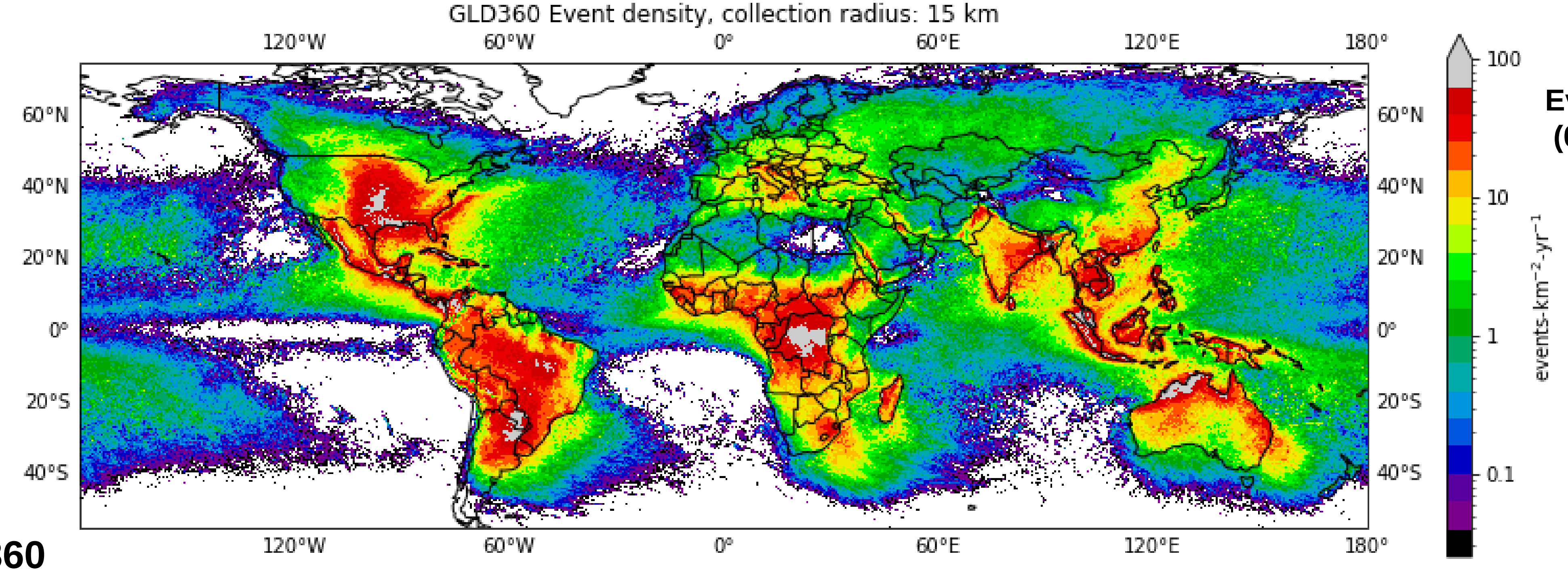
ENGLN
IC+CG



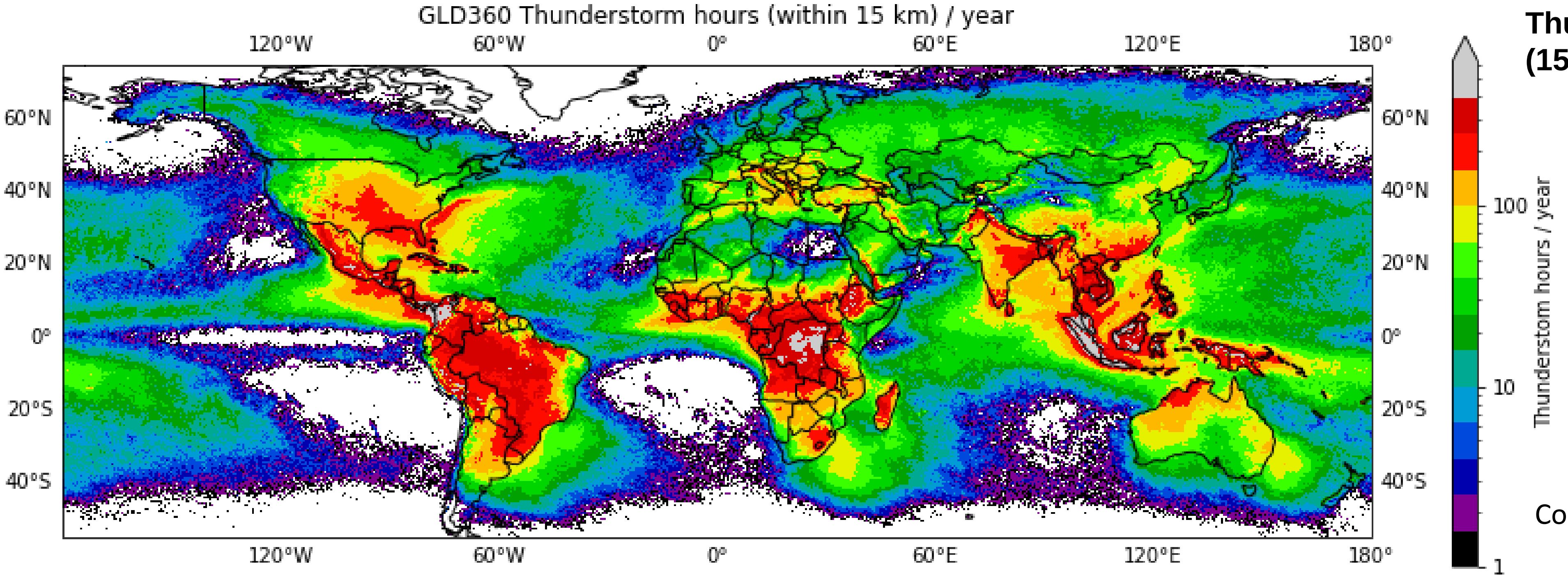
2015-2019

Mean annual ENGLN thunder hour counts for the entire globe from 2015-2019.
(DiGangi et al., 2022, BAMS Early Online Release: 10.1175/BAMS-D-20-0198.1.

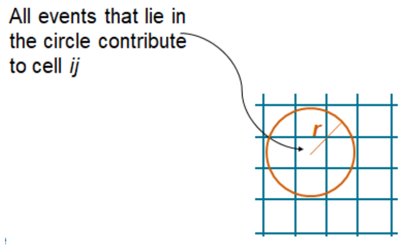
GLD360
IC+CG



Event Density 2015-2019
(0.1 deg grid)



Thunder Hours 2015-2019
(15 km radius)



Courtesy of Ryan Said, Vaisala

Metadata

- **Metadata** – Product = Total Lightning Stroke Density
    - Satellite imagers optical flash density vs ground-based RF network stroke density (Global and Regional Networks) - Complementary
    - How is satellite event/group/flash related to RF strokes?

- **Toward harmonized, consistent space and ground-based data set(s)**
    - Desire for # stations (ground-based), Detection Efficiency, resolution (time, space), and other cal/val performance parameters (e.g., network flash type – IC/CG discrimination) needed to make a climate data set most useful.
    - Note no network or space measurement is 100% DE effective over its entire coverage area.

Machine Learning and Artificial Intelligence Techniques (Future Work…)

2. Flash Type Discrimination

- **Random Forest** model classification of flashes into **Ground (CG)** or **Cloud (IC)** flashes.
- There are 21 features (Table 2) used to train the model. Two new features termed the slope and shape have been created to attempt to provide more detail about the change in the shape and magnitude of the optical emission with time.
- Random Forest with 200 trees and 80 nodes : Maximum Group Area (MGA) is most important discriminator.
- GLM observes **Total Lightning** and does not distinguish if the lightning is connecting to ground (CG) or remaining in the cloud (IC). In order to distinguish CG and IC flashes, the Random Forest model attempts to classify lightning flashes based on their size, duration, and intensity. The most important flash characteristics for distinguishing flash type are the features related to the areal size of the lightning and the time of day the lightning occurs.
- Overall, moderate success is shown when attempting to divide total lightning into CG and IC over the 2018 period. This information can be used by researchers to improve the use of GLM in the study of different storm types as well as aiding in wildfire forecasting.

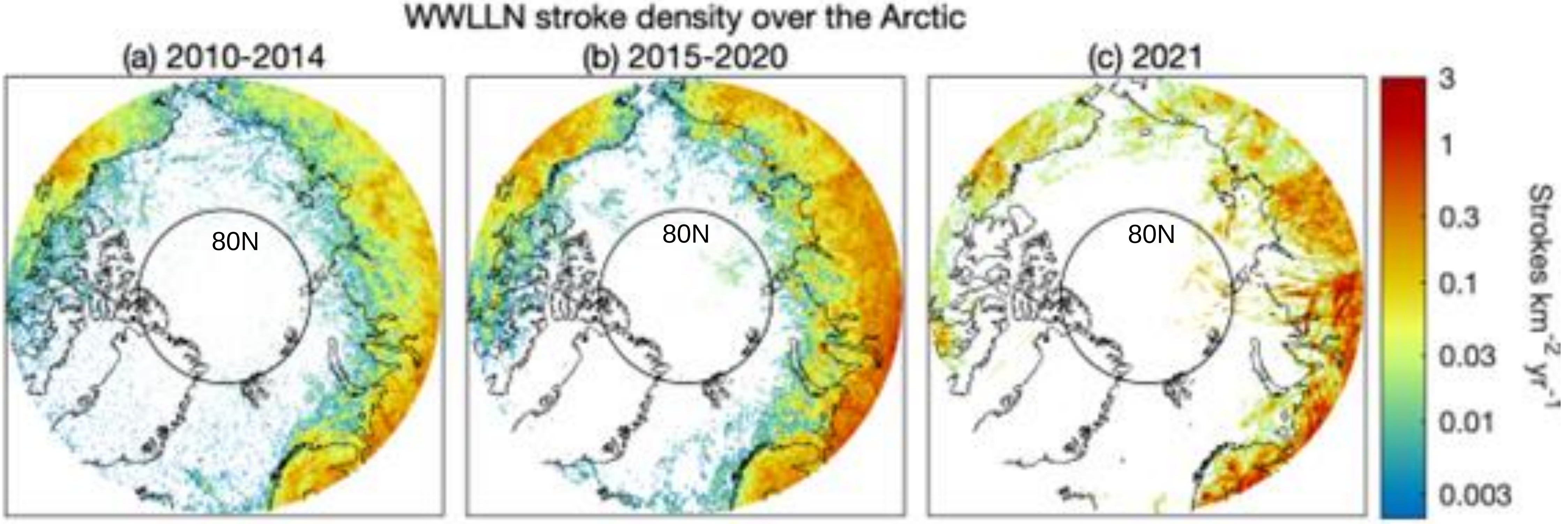
Table 2
Definitions of Geostationary Lightning Mapper (GLM) Flash Characteristics Input as Features Into the Random Forests (RF) Model

Features	Definition
Spatial features	
Maximum group area	The maximum area associated with a single group in the flash
Maximum no. of events in a group	Maximum number of events associated with a single group in the flash
Footprint	The combined area of all the events comprising a flash
Propagation	Furthest separation of groups in a GLM flash divided by the diameter of the flash
Elongation	Furthest separation of events in a GLM flash divided by the diameter of the flash
Max distance between groups	Max distance between groups in a flash
Max distance between events	Max distance between events in a flash
Child count	Number of groups in a flash
Grandchild count	Number of events in a flash
Temporal features	
Time-of-day	Time of day in UTC
Time illuminated	Amount of time GLM groups were present in a flash
Duration	Time length of flash
Max time difference	Maximum amount of time between two subsequent groups
Number of contiguous groups	Number of groups that occur successively in time
Spatiotemporal/other features	
Slope	Max energy group in 2nd half minus max energy group in 1st half divided by time difference
Shape	Number of groups in first half of flash divided by total number of groups
Energy	Total additive energy of a flash
Maximum group energy	Maximum energy associated with a group in the flash
Mean energy	Average energy for all groups composing a flash
Standard dev. of energy	The standard deviation of energy for a flash
Energy threshold	Number of groups with an energy above the average group energy for the flash

Ringhausen et al., Earth and Space Science, 10.1029/2021EA001861

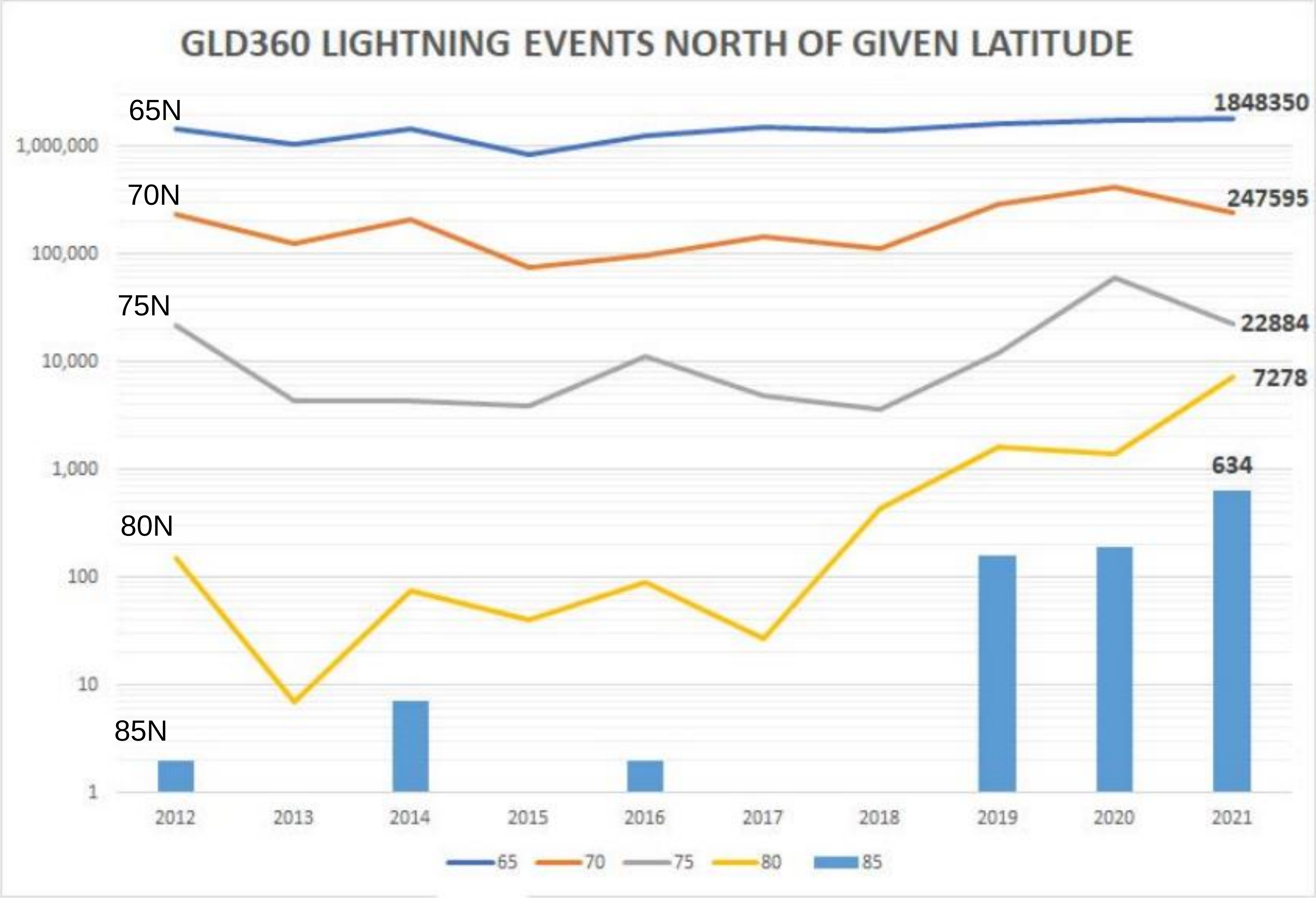
Climate Change and Adaptation

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 Issue on Climate, 2022



Courtesy Vaisala, Inc.

Projected increase in lightning strikes in the United States due to global warming

DAVID M. ROMPS , JACOB T. SEELEY, DAVID VOLLARO, AND JOHN MOLINARI
SCIENCE**,** 14 Nov 2014, DOI: 10.1126/science.1259100

Here we propose that the lightning flash rate is proportional to the convective available potential energy (CAPE) times the precipitation rate. Using observations, the product of CAPE and precipitation explains 77% of the variance in the time series of total cloud-to ground lightning flashes over the contiguous United States (CONUS). Storms convert CAPE times precipitated water mass to discharged lightning energy with an efficiency of 1%. When this proxy is applied to 11 climate models, CONUS lightning strikes are predicted to increase 12 +/- 5% per degree Celsius of global warming and about 50% over this century

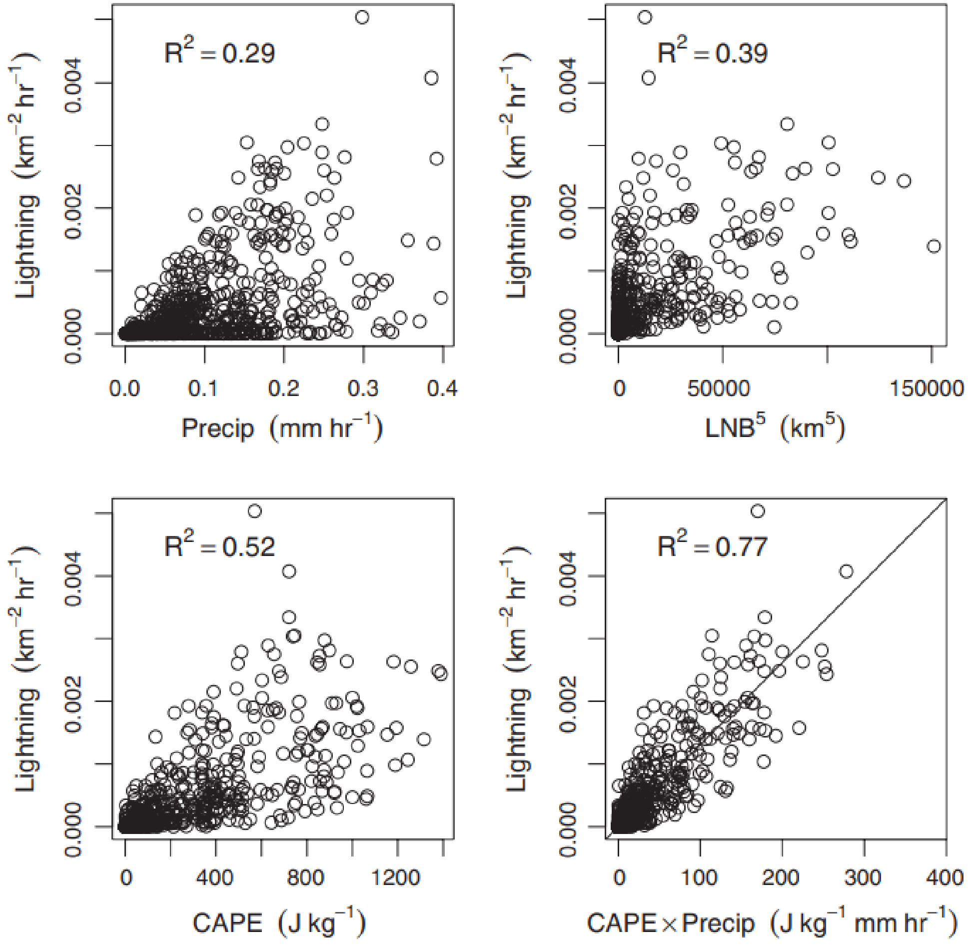


Fig. 3. Lightning versus various proposed proxies. For the year 2011, scatter plots are shown of the time series of 0 and 12 GMT CONUS mean lightning against **(top left)** precipitation, **(top right)** LNB to the fifth power, **(bottom left)** CAPE, and **(bottom right)** CAPE times precipitation.

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SCIENCE, 14 Nov 2014, DOI: 10.1126/science.1259100

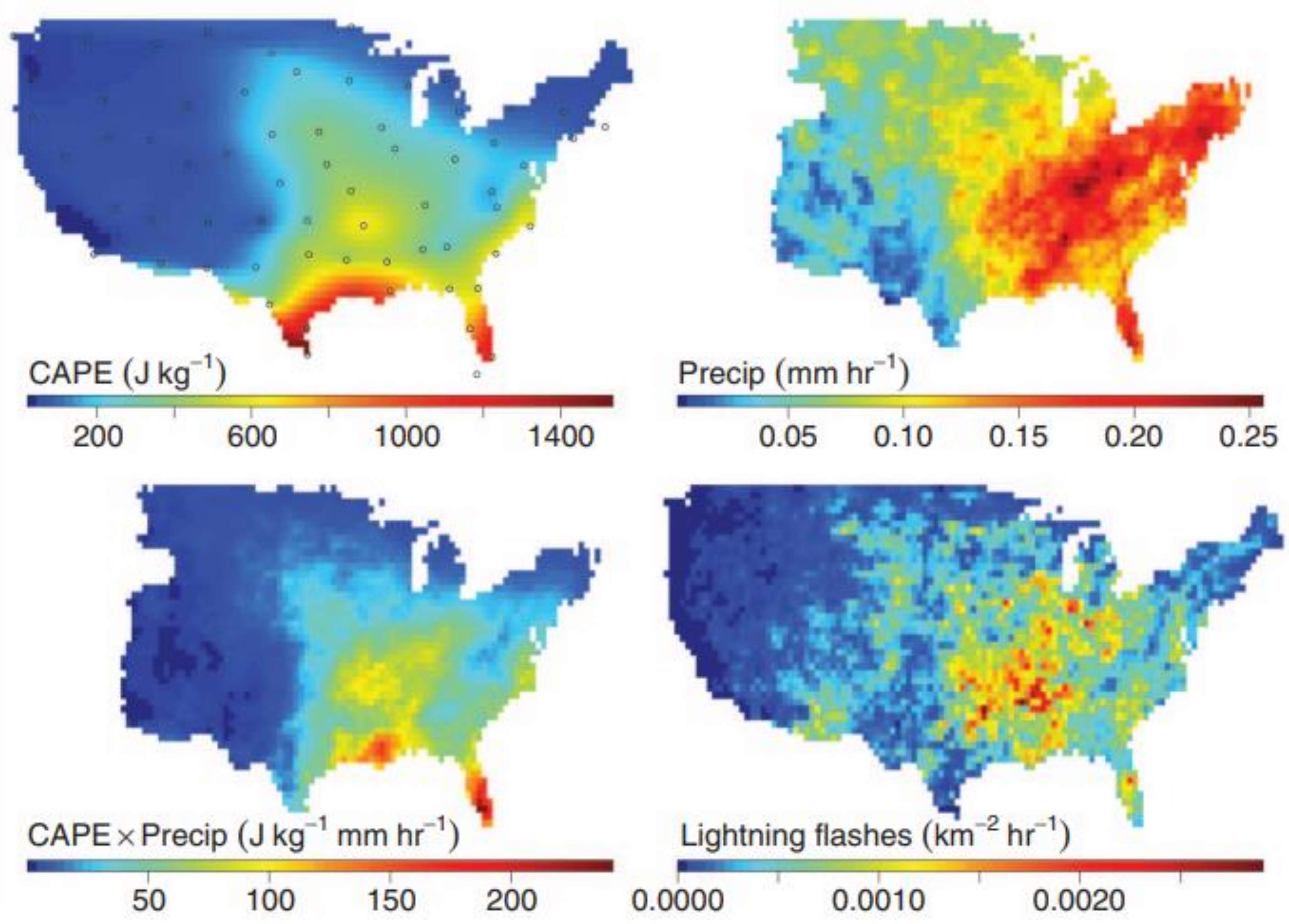


Fig. 1. Mean maps of CAPE, precipitation, CAPE times precipitation, and lightning flashes. For the year 2011, maps are shown of mean (**top left**) CAPE from the SPARC radiosonde data, (**top right**) precipitation from the National Weather Service River Forecast Center data, (**bottom left**) product of the top two maps, and (**bottom right**) CG lightning from the NLDN data. For CAPE, means are calculated by averaging all 00 and 12 GMT soundings; circles denote the locations of radiosonde releases. For precipitation and lightning, means are calculated by averaging over 22-02 and 10-14 GMT.

Future increases in Arctic lightning and fire risk for permafrost carbon

Yang Chen, David M. Romps, et al., in Nature Climate Change, May 2021,
https://doi.org/10.1038/s41558-021-01011-y

Lightning is an indicator and a driver of climate change. Here, using satellite observations of lightning flash rate and ERA5 reanalysis, we find that the spatial pattern of summer lightning over northern circumpolar regions exhibits a strong positive relationship with the product of convective available potential energy (CAPE) and precipitation. Applying this relationship to Climate Model Intercomparison Project Phase 5 climate projections for a high-emissions scenario (RCP8.5) shows an increase in CAPE (86 ± 22%) and precipitation (17 ± 2%) in areas underlain by permafrost, causing summer lightning to increase by 112 ± 38% by the end of the century (2081–2100). Future flash rates at the northern treeline are comparable to current levels 480 km to the south in boreal forests. We hypothesize that lightning increases may induce a fire–vegetation feedback whereby more burning in Arctic tundra expedites the northward migration of boreal trees, with the potential to accelerate the positive feedback associated with permafrost soil carbon release.

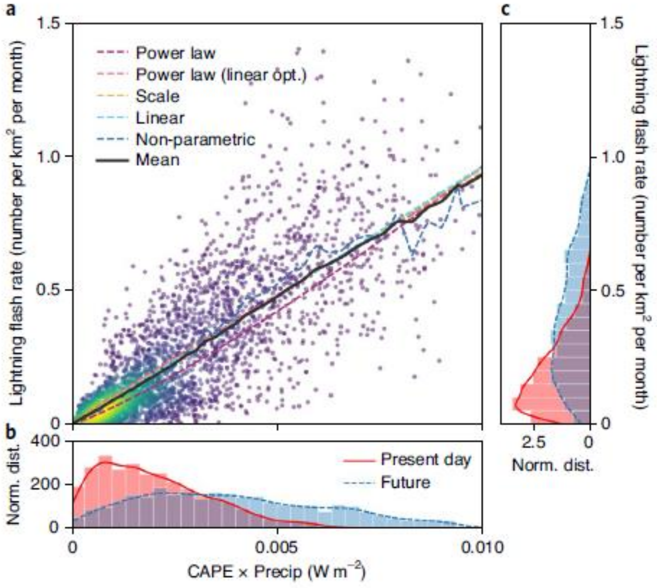
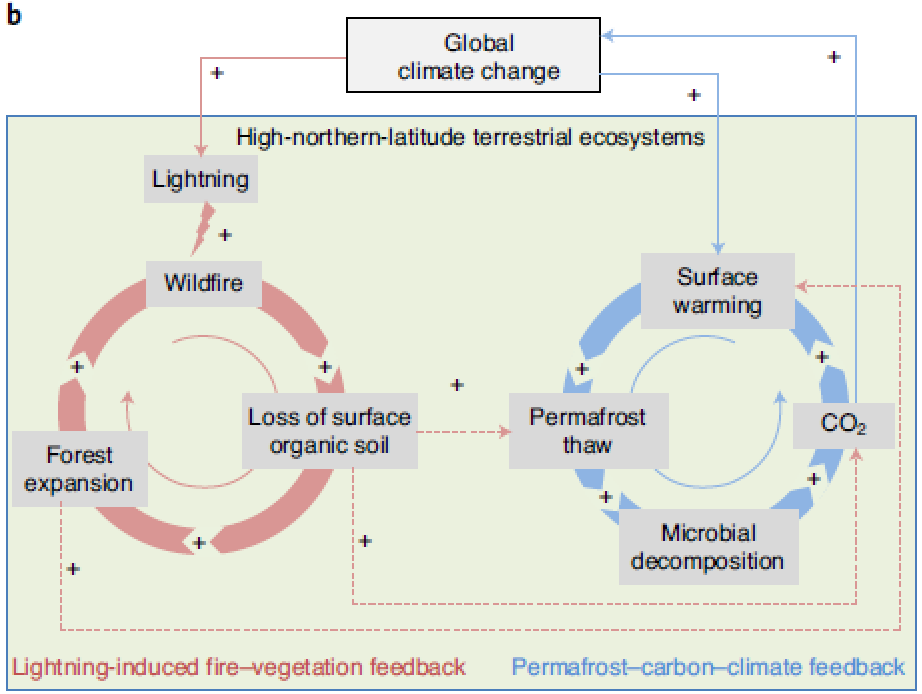


Fig. 1 | Contemporary lightning flash rates across high-northern-latitude regions are positively correlated with the product of CAPE and Precip.



Lightning and Renewable Energy: Risk to Wind Turbines

reNEWS.BIZ
(https://renews.biz/)

(https://renews.biz/62355/lightning-related-blade-problem-strikes-vestas/#sidr)

Turbine blade issues related to "high intensity lightning" were behind Vestas' extraordinary warranty costs of €175m in the second quarter of the year.

Wind turbines trigger lightning during heavy snowstorm

A major lake-effect snowstorm hit the Eastern Great Lakes of North America on November 17–21, 2022, as cold air rushed across the warm, unfrozen lakes. The snow bands that developed resulted in over two meters (80 inches) of snowfall near Buffalo, New York.

DID YOU KNOW?
Lightning that occurs while snow is falling is called thundersnow.

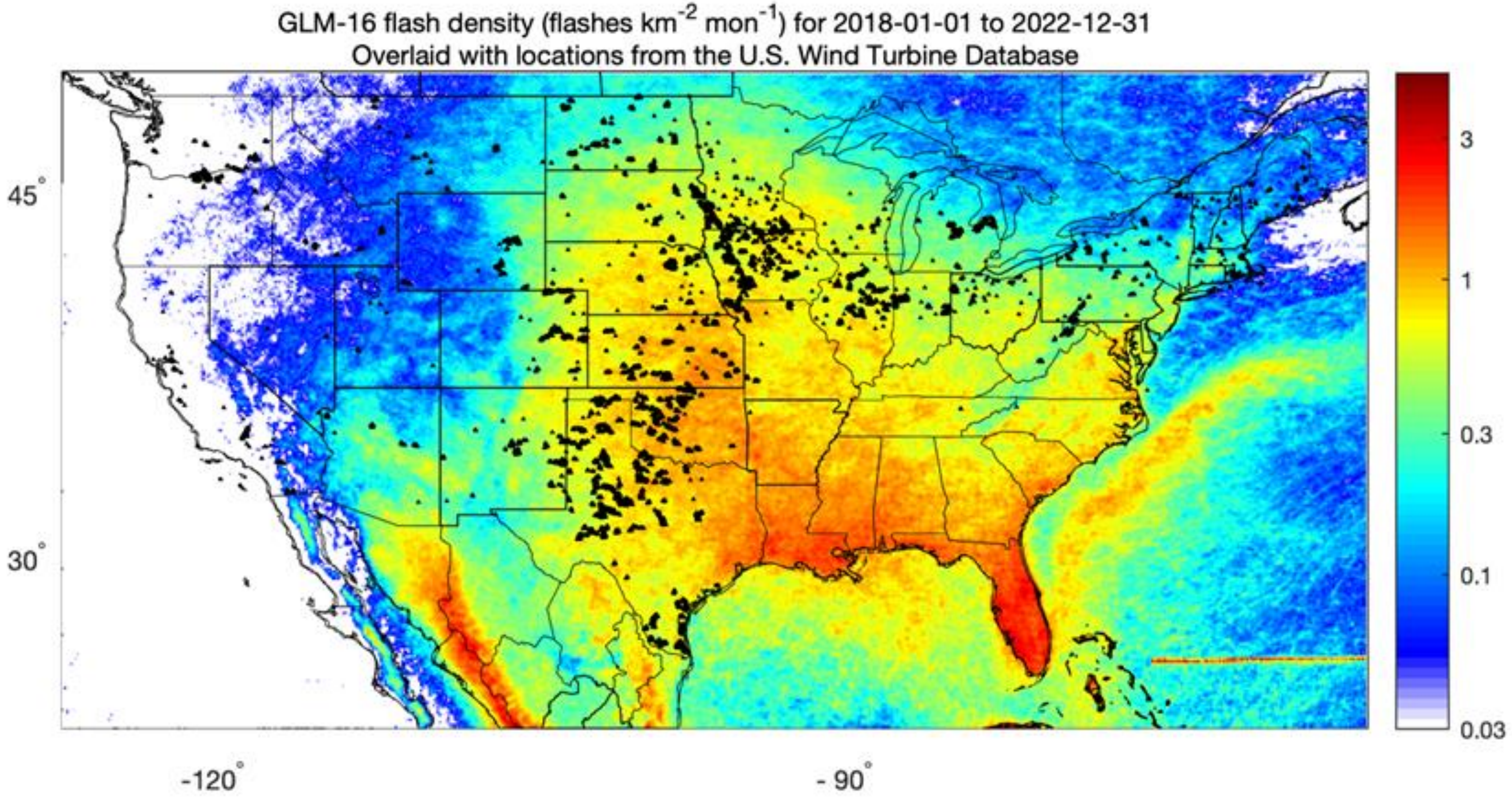
This snowstorm was also a prolific producer of thundersnow. Across the Eastern Great Lakes, Vaisala's National Lightning Detection Network detected more than 1,100 lightning events over three and a half days. Many of these events were near wind turbines, which can trigger lightning when winter storms move overhead.

Lightning concentrated near wind farm
Just south of Buffalo, New York, 184 lightning events were detected at a wind farm in just 28 hours—almost matching the amount of lightning that occurred there during the first ten and a half months of the year!

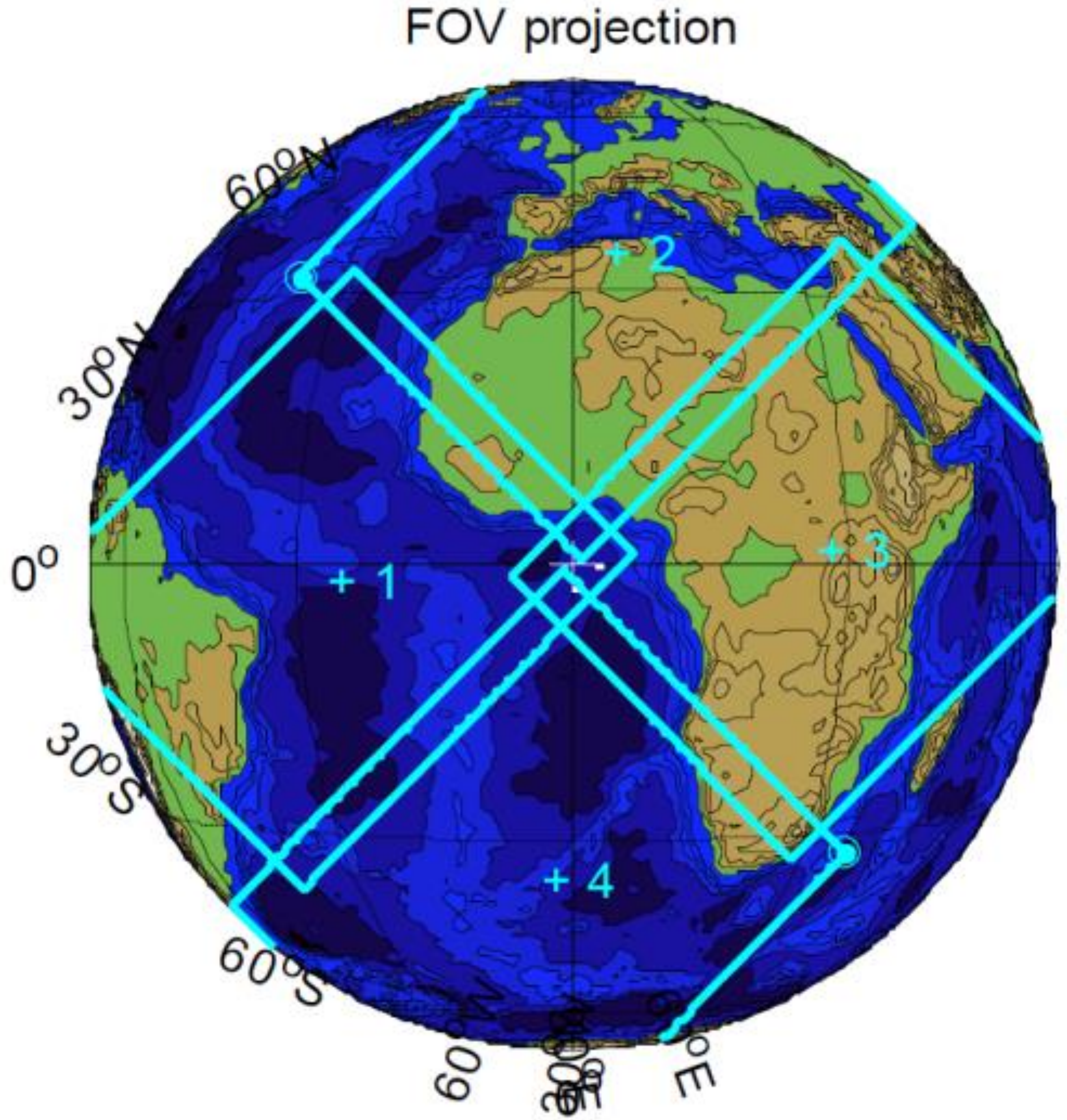
Lightning can damage wind turbine blades and hubs. Accurate lightning data helps operators know when to inspect and maintain turbines to ensure safe, efficient operations.

Vaisala, Inc.

Lightning Climatology and Wind Turbines

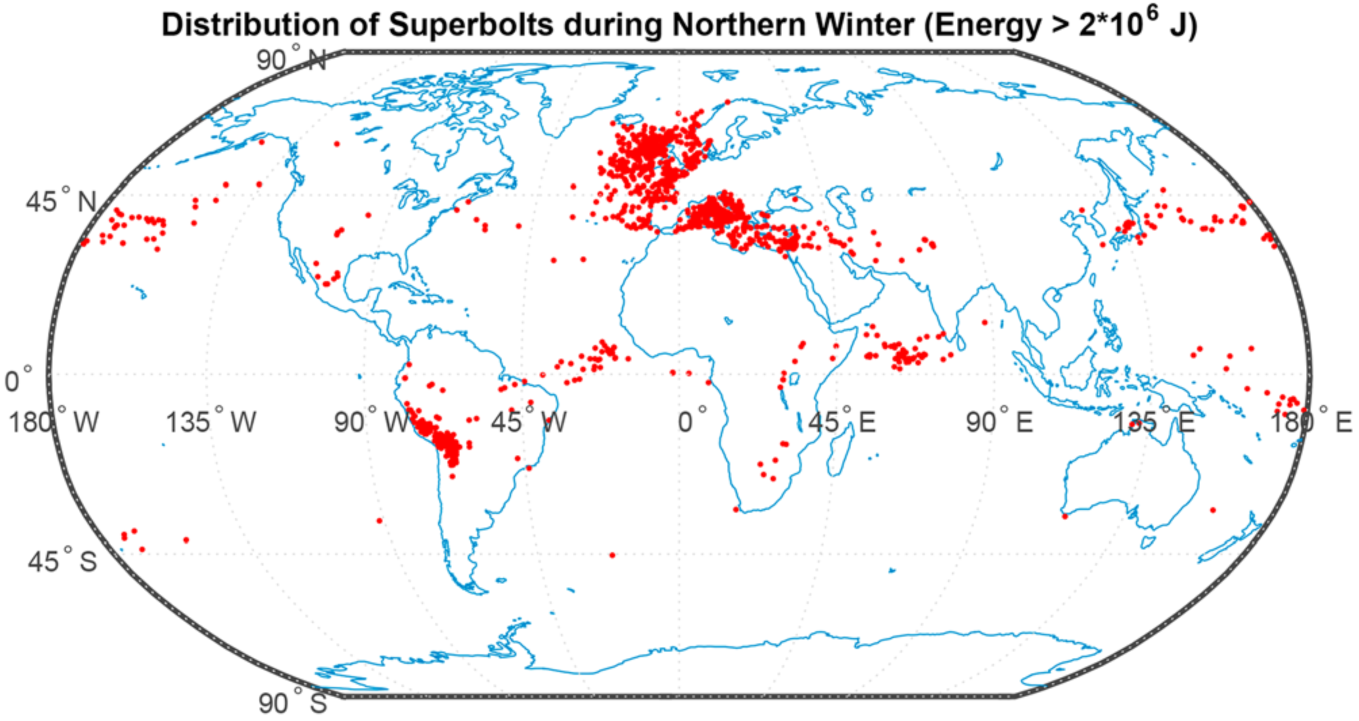


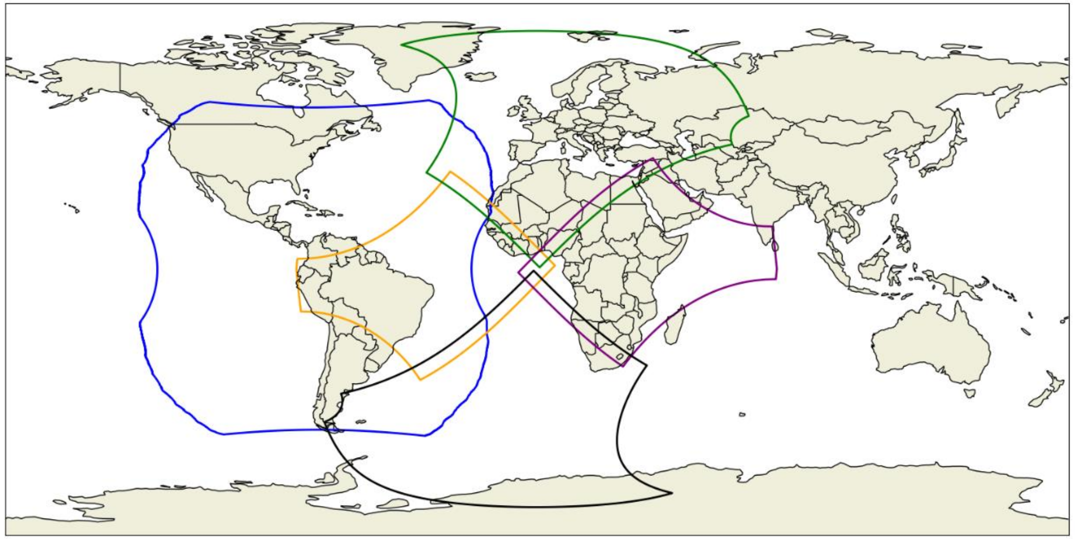
MTG I-1 Geo Lightning Imager Coverage
Meteosat Third Generation commissioning began March 1



Why is Wintertime Oceanic Lightning More Energetic?

MTG will provide continuous lightning observations from space of the wintertime storms in the Mediterranean





FOV of GLM on GOES-16 (blue) and FOV of the four cameras of MTG-LI (west in yellow, north in green, east in purple, and south in brown, respectively)

Lightning enhancement over major oceanic shipping lanes

Thornton, J. A., K. S. Virts, R. H. Holzworth, and T. P. Mitchell (2017),
Geophys. Res. Lett., 44, 9102–9111, doi:10.1002/2017GL074982.

AGU Geophysical Research Letters 10.1002/2017GL074982

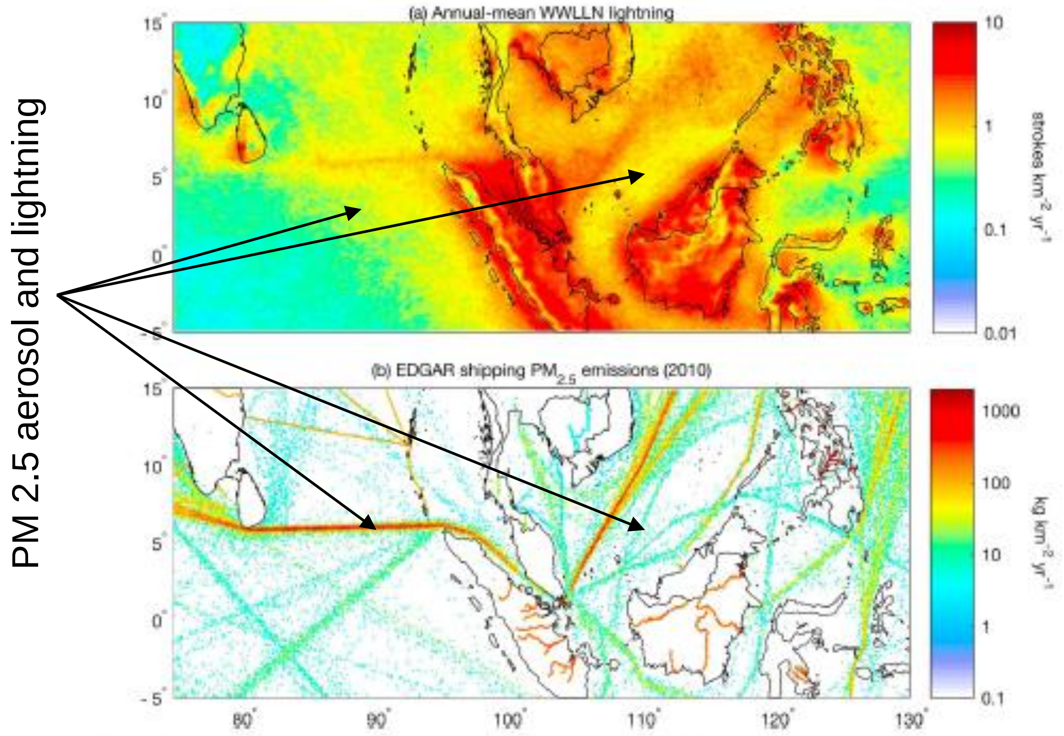
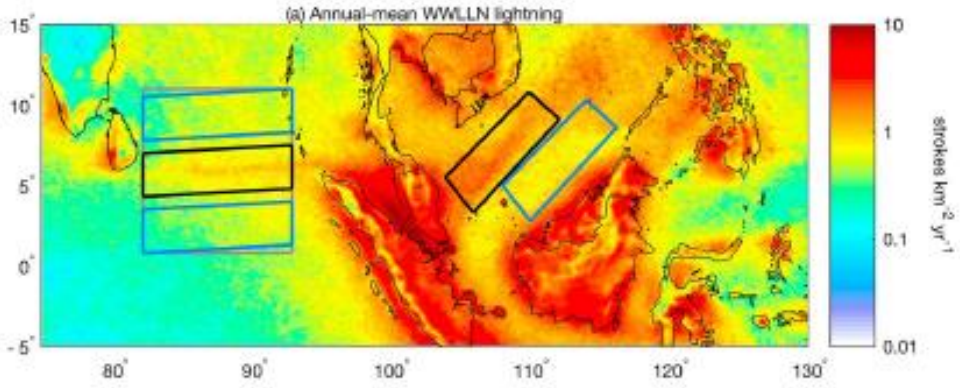


Figure 1. (a) Observed annual-mean WWLLN lightning density for 2005–2016 in the eastern Indian Ocean and the South China Sea. (b) $PM_{2.5}$ shipping emissions estimates from EDGAR database for 2010, both at 0.1° resolution. See text and SI for more details.

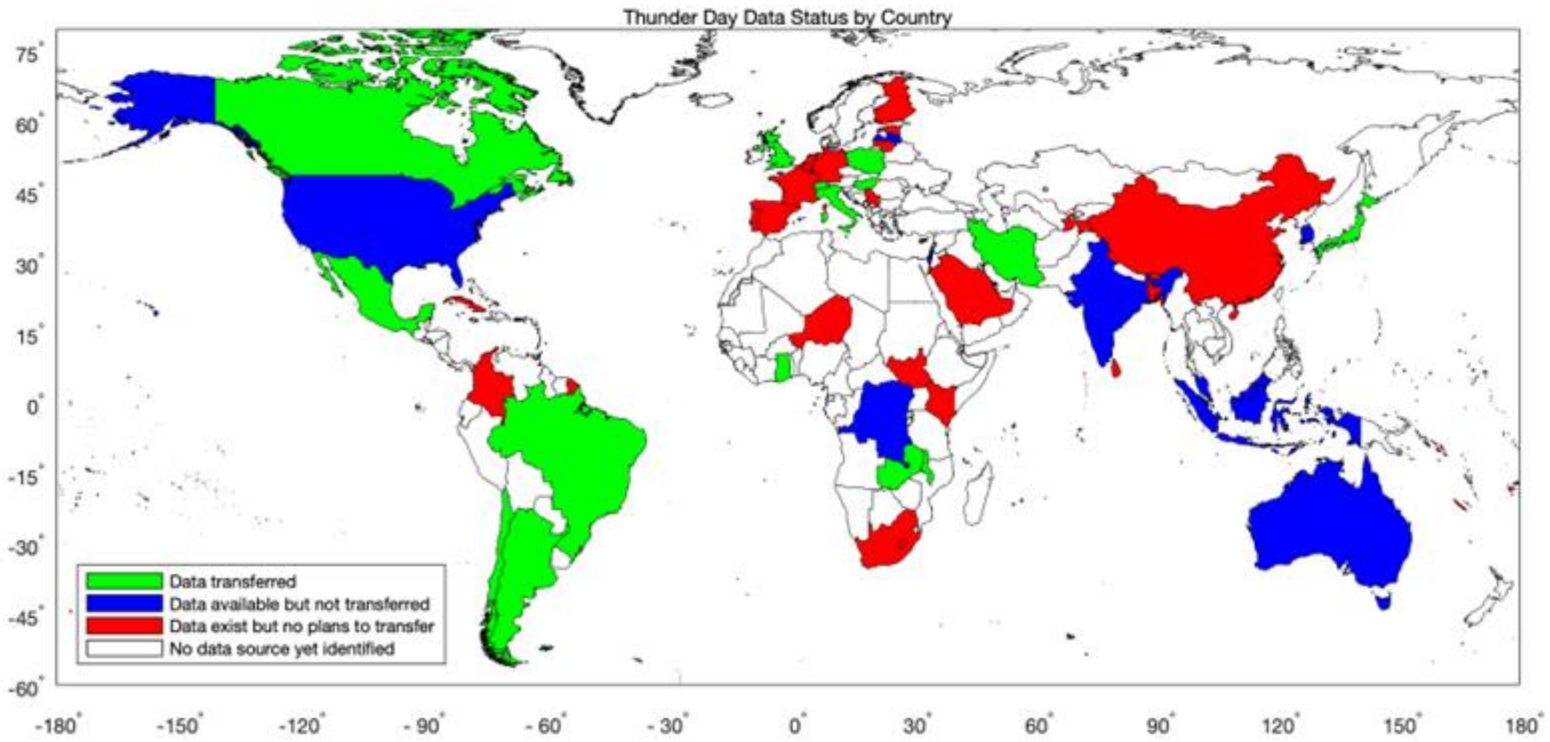


Shipping lanes denoted by black polygons

Thunder Day Records

Status:
TTLOCA requests 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.



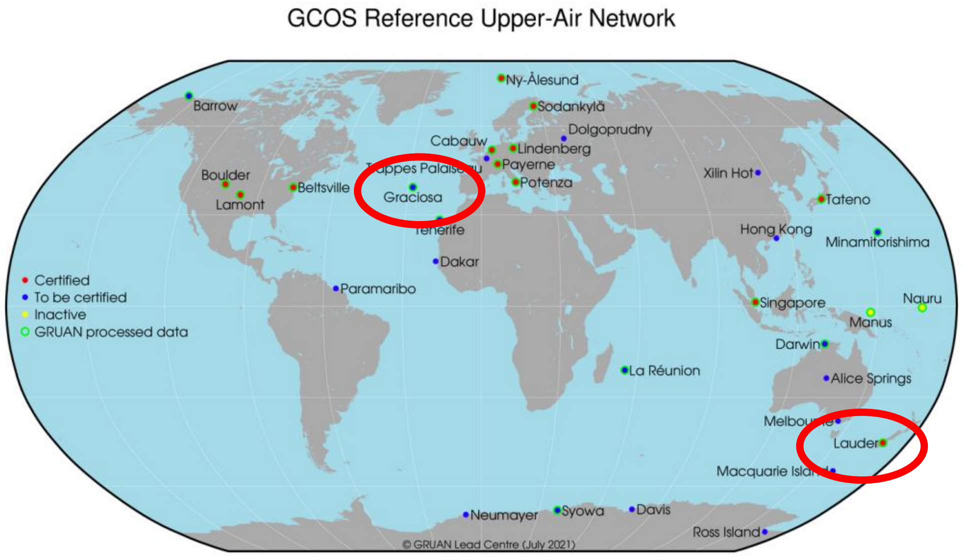
Two-station Measurements of the Ionospheric Potential with GRUAN

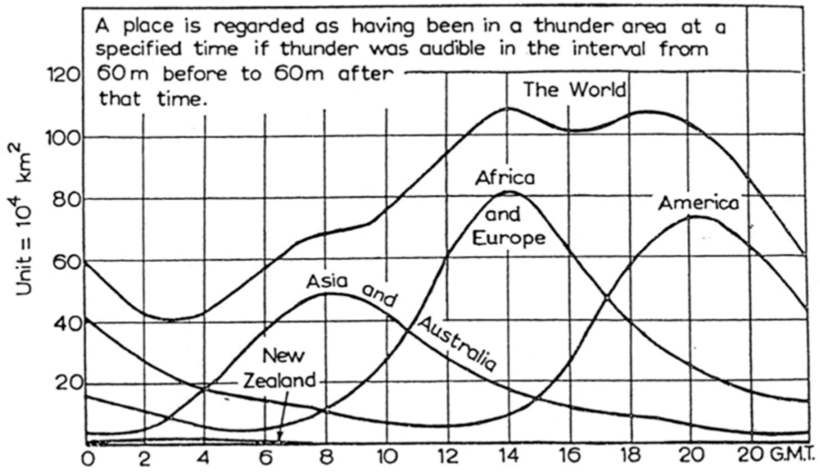
Status:
The E field instrument built by Quasar is ready for field testing with collaborators in June.

Tests with tethered balloon and ultimately with free balloon sounding if things work well.

If successful, E. Williams and collaborators will go to the two GRUAN sites on islands (Graciosa in Atlantic and southern Island of New Zealand, Lauder site, in Pacific) to train people there to make simultaneous soundings with the new equipment.

A second collaboration with electrometer experts at Analog Devices Inc
Plans to build an inexpensive electrometer circuit for making E field soundings (a voltage measurement rather than the Quasar E field measurement). This method depends on polonium probes. This method was forbidden at Graciosa, but has been allowed in New Zealand so planning comparative measurements eventually.





Long-standing puzzlement about the global electrical circuit: Africa vs America (electrified showers, pollution-aerosols)

Summary

- **Lightning is a global Natural Hazard** of great importance and interest
- **Exemplary lightning datasets –** evaluating candidate data sets (satellite – Ground-Based RF)
    - Thunder Hour (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

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

- 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.