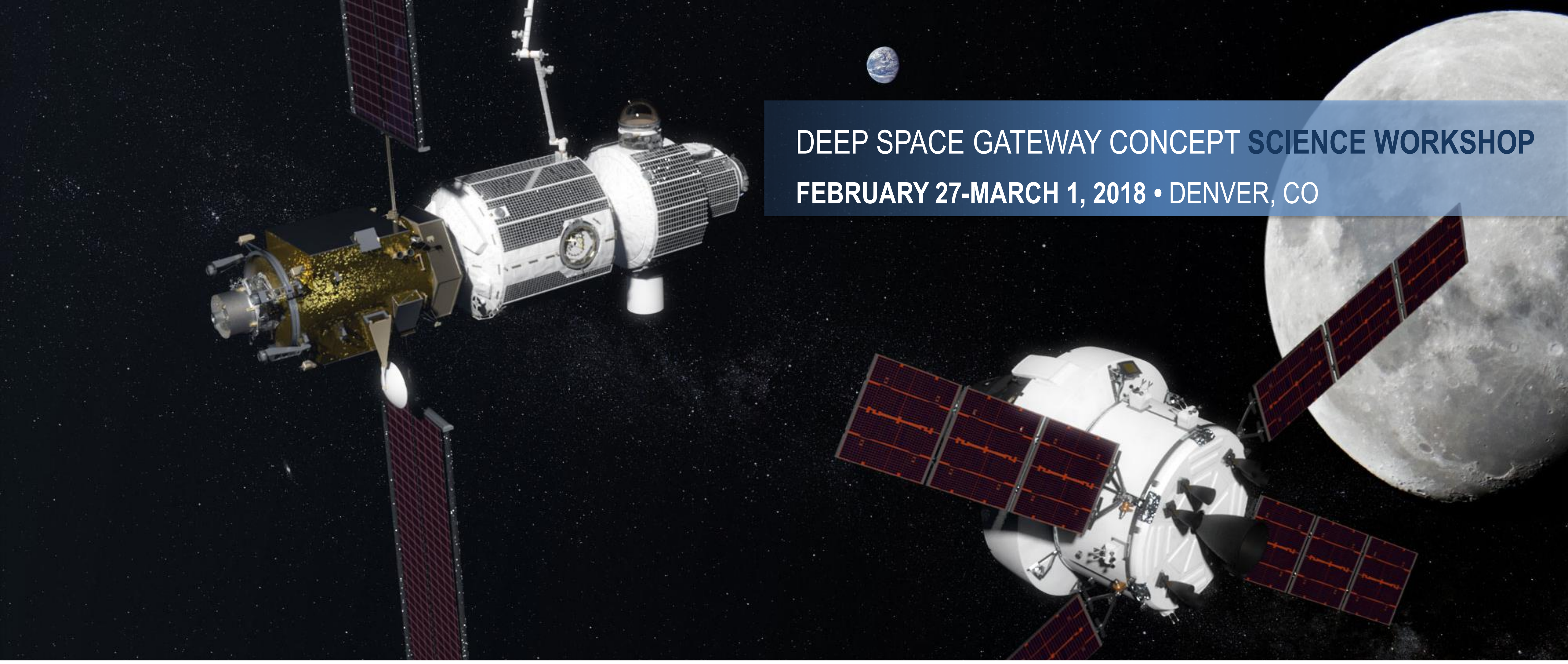


The Deep Space Gateway Lightning Mapper (DLM):

Monitoring Global Change and Thunderstorm Processes through Observations of Earth's High-Latitude Lightning from Cis-Lunar Orbit

28 February 2018

Timothy Lang, Research Aerospace Technologist, NASA Marshall Space Flight Center

Instrument Function Statement and Gateway Usage

STATEMENT	INSTRUMENT/CONCEPT DETAILS
FUNCTION STATEMENT	Monitor global change and thunderstorm processes through observations of Earth’s high-latitude lightning. This instrument will combine long-lived sampling of individual thunderstorms with long-term observations of lightning at high latitudes. • How is global change affecting thunderstorm patterns? • How do high-latitude thunderstorms differ from low-latitude?
WHY IS THE GATEWAY THE OPTIMAL FACILITY FOR THIS INSTRUMENT/RESEARCH?	• Expected DSG orbits will provide nearly continuous viewing of the Earth’s high latitudes (50 deg and poleward) • These regions are not well covered by existing lightning mappers (e.g., Lightning Imaging Sensor / LIS, or Geostationary Lightning Mapper / GLM) • Polar, Molniya, Tundra, etc. Earth orbits have significant drawbacks related to continuous coverage and/or stable FOVs

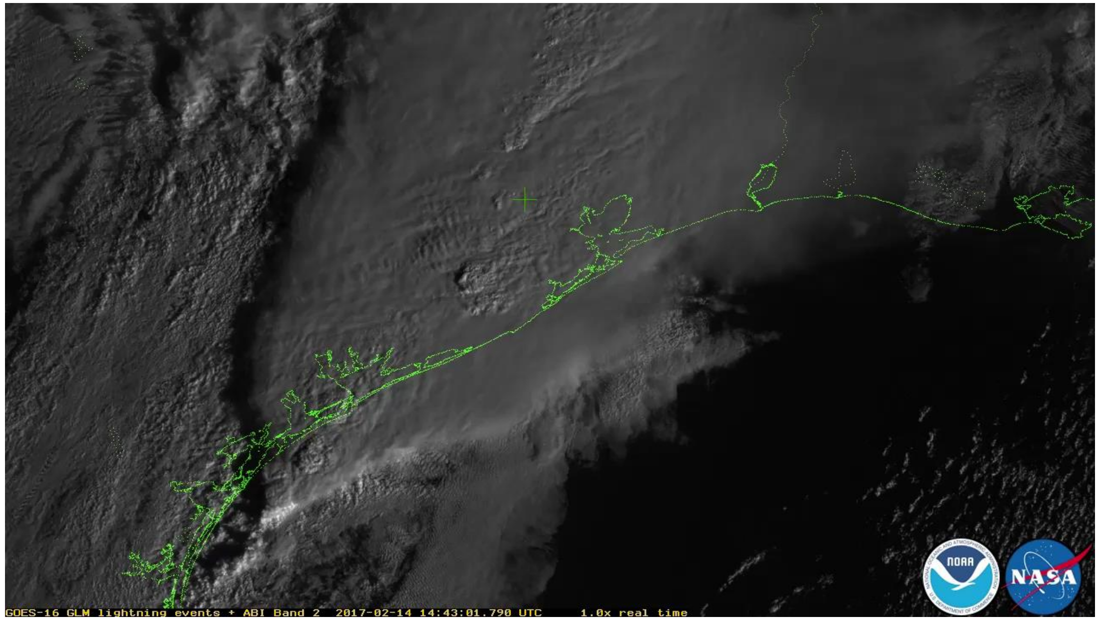
Basic Instrument Parameters

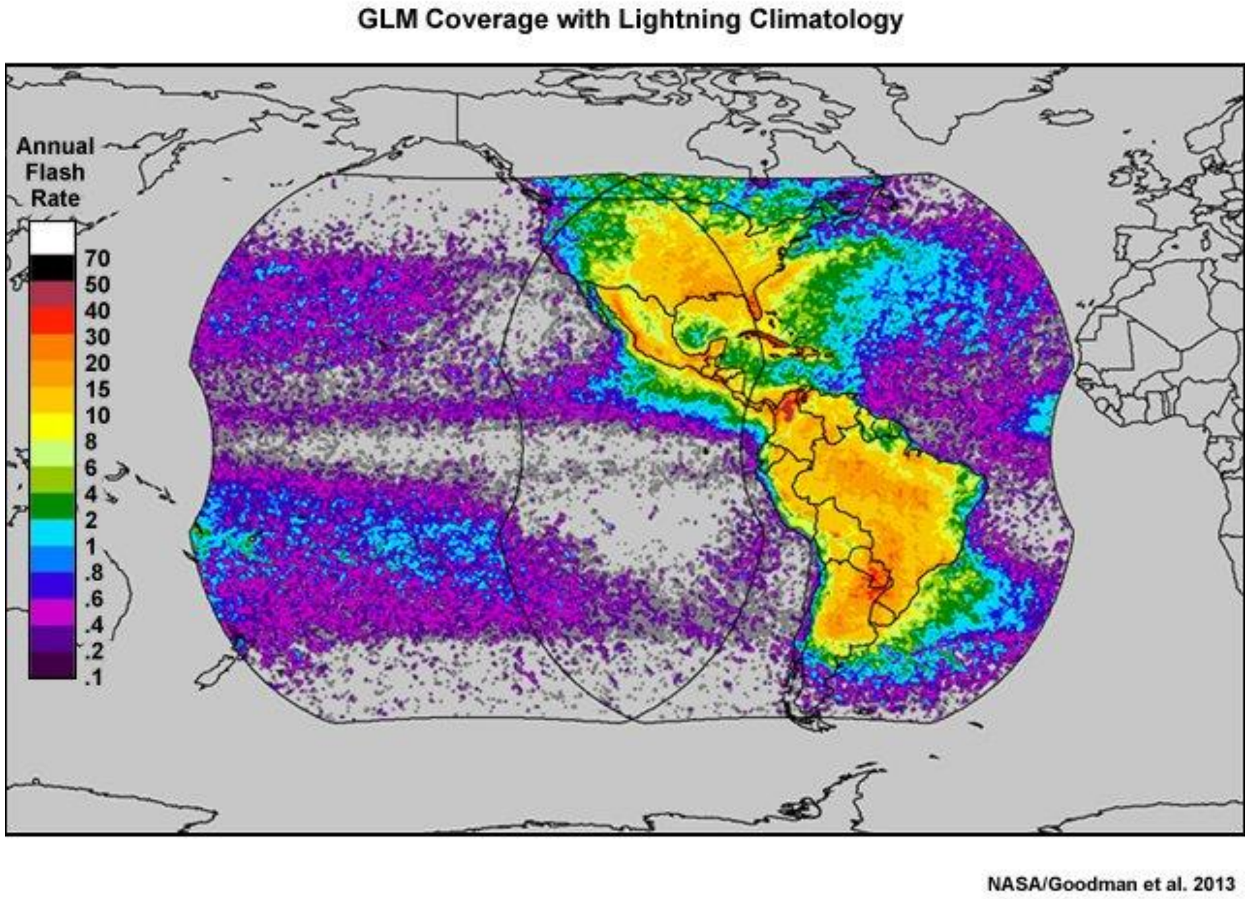
PARAMETER	INSTRUMENT ESTIMATE & ANY COMMENTS
MASS (KG)	200 kg
VOLUME (M)	1.0 x 1.2 x 1.2 m^3 (switch to reflector telescope to reduce physical length)
POWER (W)	100 W
THERMAL REQUIREMENTS	Need facility/orbit details; greatest need - focal plane not overheating; CMOS mitigates this
DAILY DATA VOLUME	100 GB
CURRENT TRL	4 (working prototypes currently in orbit, but need to adapt for increased viewing distance)
WAG COST & BASIS	$50M minimum, based on lessons learned from LIS and GLM
DURATION OF EXPERIMENT	Open-ended
OTHER PARAMETERS	N/A

Instrument Gateway Usage

USAGE	INSTRUMENT REQUIREMENTS & COMMENTS
ORBIT CONSIDERATIONS	Most NRHOs are fine, L1 North would be ideal for boreal forest coverage
FIELD OF VIEW REQUIREMENTS	Earth in FOV nearly continuously, high pointing accuracy (gimbal system?)
REQUIRES USE OF AIRLOCK	No
CREW INTERACTION REQUIRED?	During install only (a few hours based on ISS-LIS experience)
WILL ASTRONAUT PRESENCE BE DISRUPTIVE?	Will need technical solution to compensate for micro-vibrations
DOES THE INSTRUMENT PRESENT A RISK TO THE CREW	No
OTHER CONSUMABLES REQUIRED	None
SPECIAL SAMPLE HANDLING REQUIREMENTS	None
NEED FOR TELEROBOTICS?	During install only, if astronaut does not manually install
OTHER REQUIREMENTS OF THE GATEWAY?	Prefer good attitude control

References and Status of Work in this Field





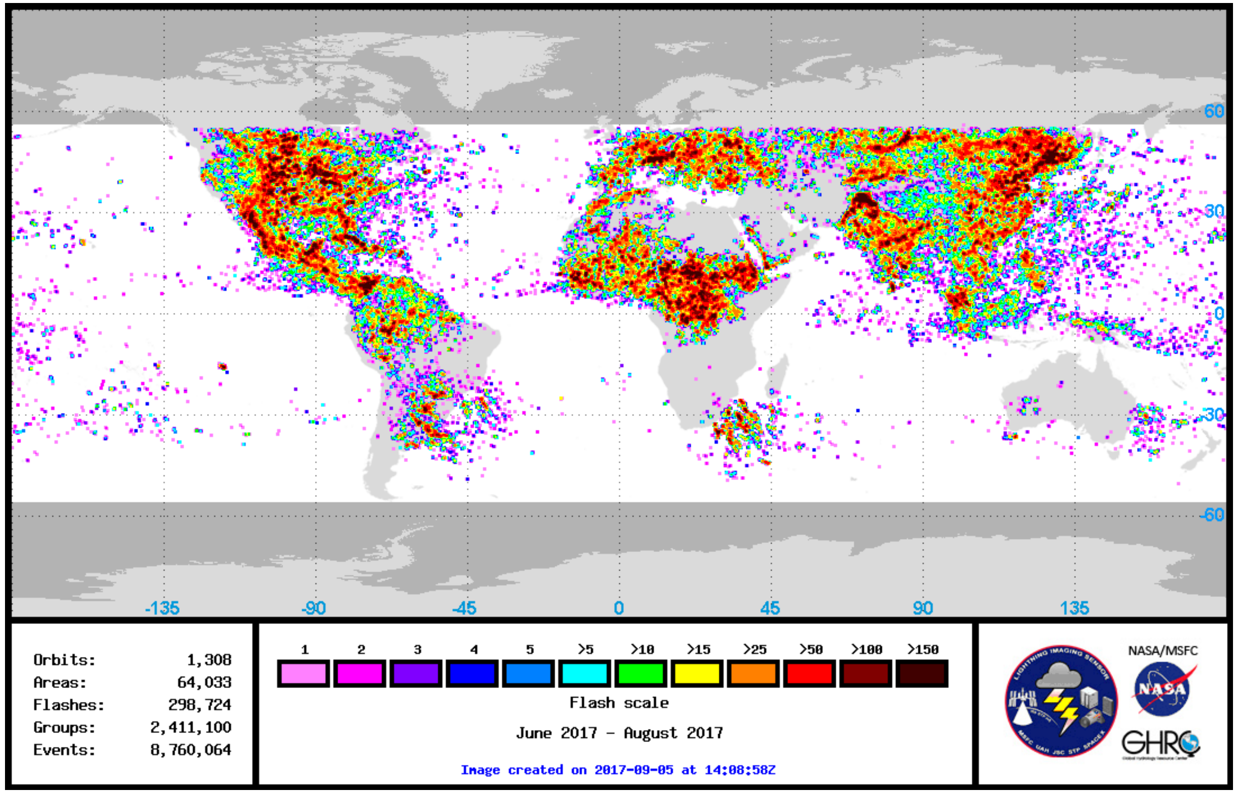
Geostationary Lightning Mapper

- Demonstrates feasibility of lightning detection well beyond LEO (>> 50x distance)
- Similar instruments on Chinese FY-4 series, Meteosat 3rd Generation
- Poor coverage of upper latitudes

S. J. Goodman et al., The GOES-R Geostationary Lightning Mapper (GLM), Atmospheric Research, Vol. 125–126, 2013, Pages 34-49, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2013.01.006.

References and Status of Work in this Field

NASA

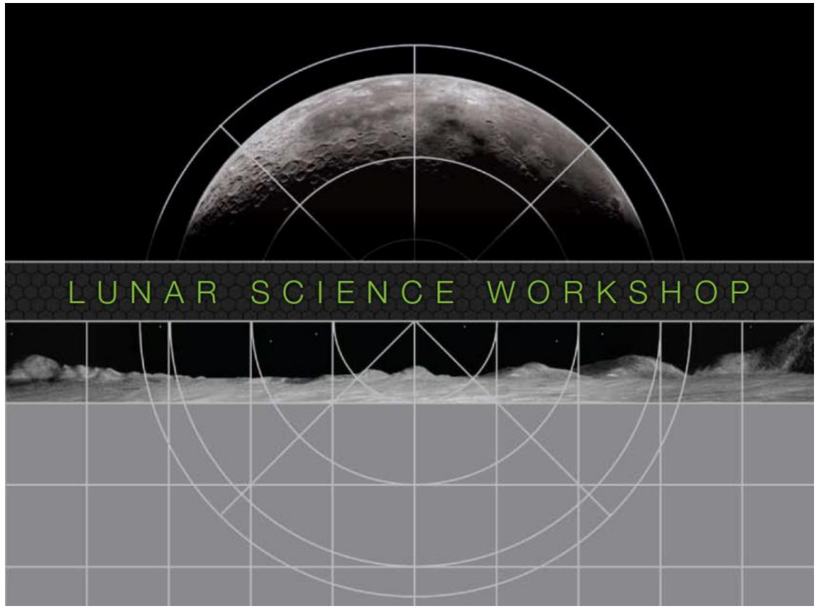


LIS Science Team and NASA GHRC

Lightning Imaging Sensor (LIS) on the ISS

- Demonstrates feasibility of continuous lightning observations from crew-inhabited platform
- Increased latitudinal coverage from TRMM-LIS, but still poor high-latitude sampling
- *Blakeslee et al. (2017; AGU Fall Meeting)*

References and Status of Work in this Field



NASA ADVISORY COUNCIL WORKSHOP ON SCIENCE ASSOCIATED WITH THE LUNAR EXPLORATION ARCHITECTURE

FEBRUARY 27–MARCH 2, 2007 • TEMPE, ARIZONA

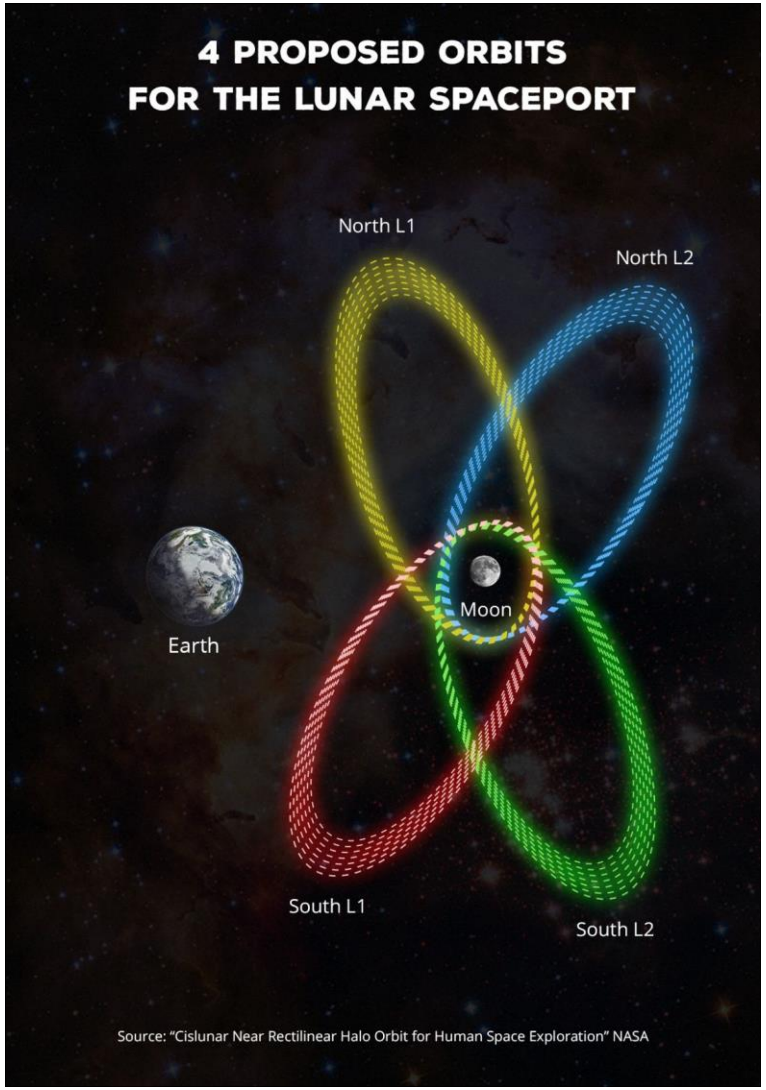
Highest final technical assessment

Highest science ranking

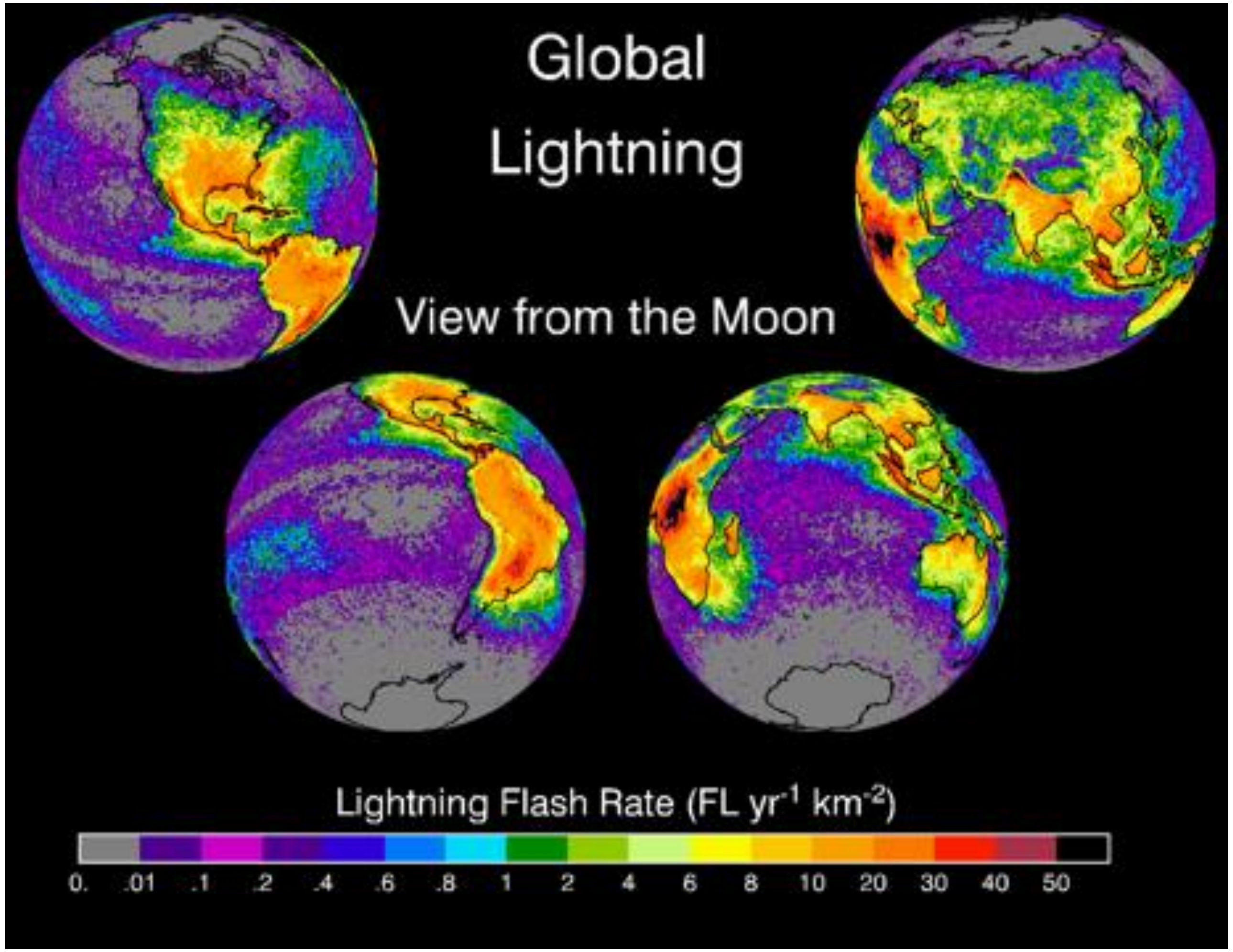
mEO12	Observe Lightning on the Earth	[[5] / [2] / [1]	A narrow band (0.774 µm) detector with 10 km spatial resolution for detection and mapping of lightning for climatology, monitoring, and hazard mitigation (tornadoes, severe storms, etc.). Full Earth views are critical, but the telescope could be as small as 50-100 cm (hence, the improved [2] / [1] ranking).	[A]

Previous assessments have found high utility and feasibility for lunar-based observations of lightning

Backup/Additional Information

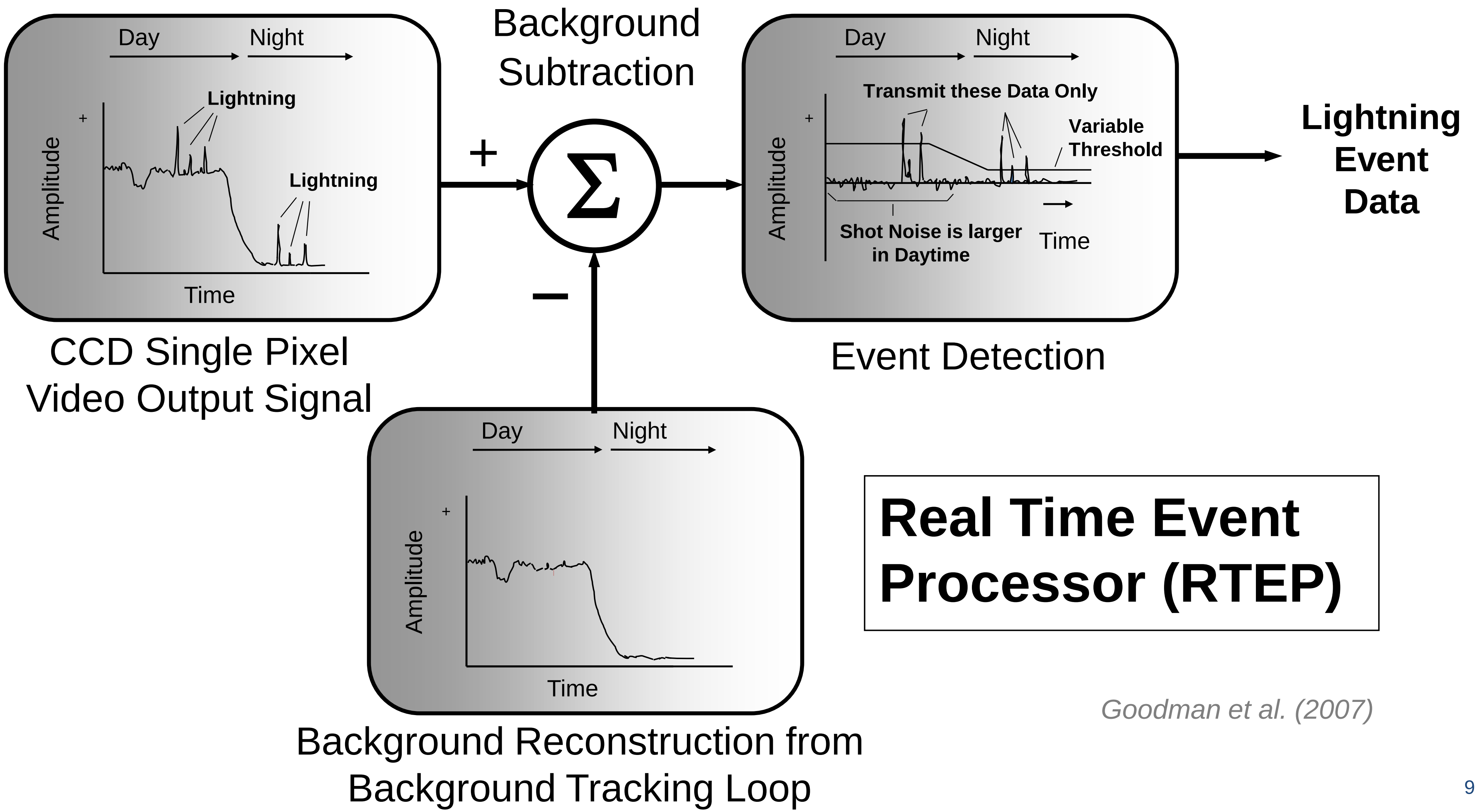


NASA



Goodman et al. (2007)

Measurement: Background Subtraction & Event Detection



Real Time Event Processor (RTEP)

Goodman et al. (2007)

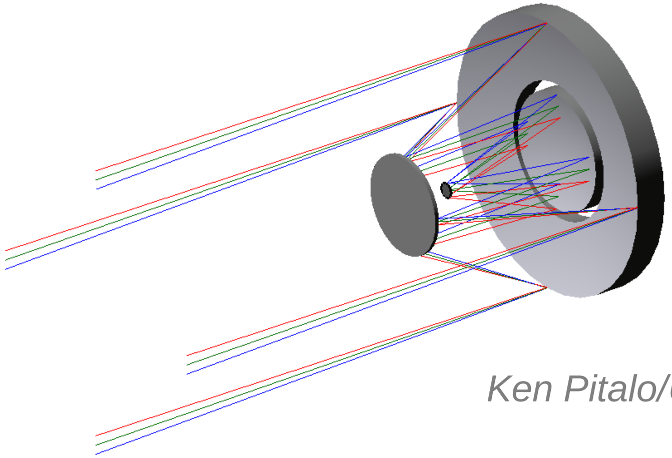
Backup/Additional Information

IFOV	10 km
CMOS Focal Plane	1372 x 1300 pix
Pixel Size	30 um
Quantum Efficiency	.85
Optical System Transmission	.70
Filter Center Wavelength	777.4 nm
Filter Bandwidth	10 A
Frame Integration	2 ms
Sample Rate	500 frames per sec

Adapted from Goodman et al. (2007)

Reflector Telescope Concept

(LIS/GLM measurement heritage - continuous, day/night, storm-scale, near-uniform observation)



Ken Pitalo/UAH

Three Mirror Anastigmat: EFL = 1500 mm: F/# = 1.25; Focal Plane Radius = 26.22 mm

Sampling Considerations

- Assuming orbit locked to moon, Earth phases and relative pointing of poles toward moon will vary monthly/annually

- Enables sampling of diurnal cycle of lightning over a long-term basis

- Enables long-lived sampling of individual thunderstorms (until Earth rotates them out of view)

- Thus, lunar-orbiting instrument can address scientific questions related to both climate **and** storm processes

Stellarium

Backup/Additional Information

Relevance to NASA and 2017 Decadal Survey

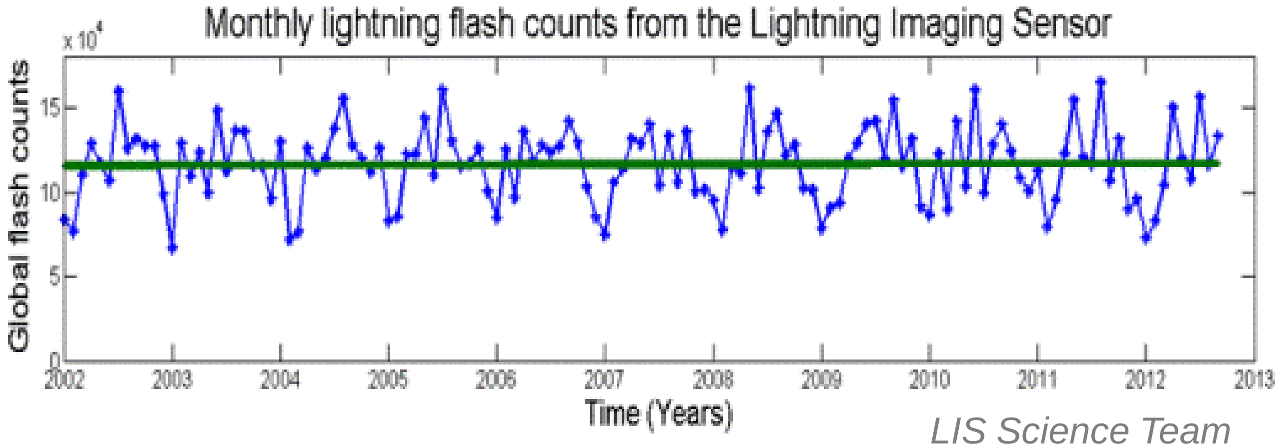
- Lightning observations directly address NASA Earth Science focus areas of Weather (including Extreme Events), Climate, and Atmospheric Composition (NO_x production)
- Decadal Survey puts "Clouds, Convection, and Precipitation" and "Ozone and Trace Gases" in the highest tiers for targeted observations. Lightning data provide quantitative information/context highly relevant to both.
- WMO has declared lightning as a new Essential Climate Variable. Lightning also important for the NCA (*Koshak et al. 2015*).

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, and Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of sources and sinks	Multispectral short wave IR and thermal IR sounders; or lidar**		X	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		X	
Ocean Surface Winds and Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift	Doppler scatterometer		X	
Ozone and Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/Vis/IR microwave limb/nadir sounding and UV/Vis/IR solar/stellar occultation		X	
Snow Depth and Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation and forest degradation	Lidar**		X	
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and	Active sensing (lidar, radar, scatterometer); or passive imagery		X	X

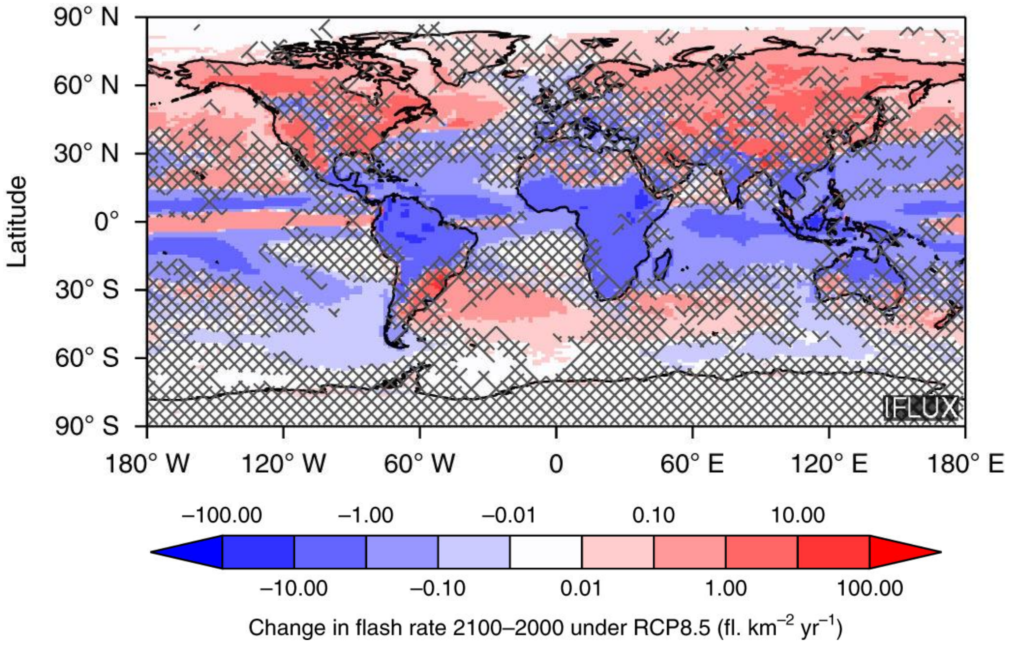
The National Academies Press

Global Change and Lightning

- There continues to be fundamental disagreement in the literature about whether lightning will increase or decrease under various warming scenarios (e.g., *Romps et al. 2014*, *Finney et al. 2018*)
- TRMM-LIS showed no significant trend in tropical lightning during its time in orbit
- Recent work suggests lightning maybe be changing in high latitudes in response to warming (e.g., *Veraverbeke et al. 2017*), but we lack good observations in these regions
- Major future impacts on boreal forest fires possible. We need more high-latitude lightning data!

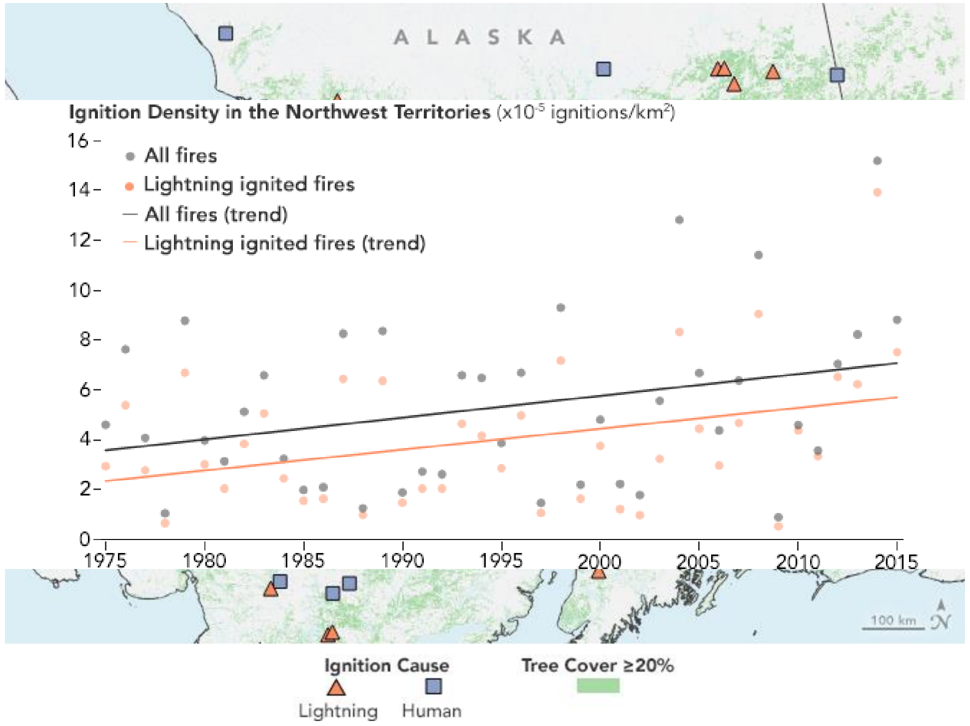


LIS Science Team



Finney et al. 2018

End Users For High-Latitude Lightning Data



Adapted from Calef et al. 2017, *Forests*

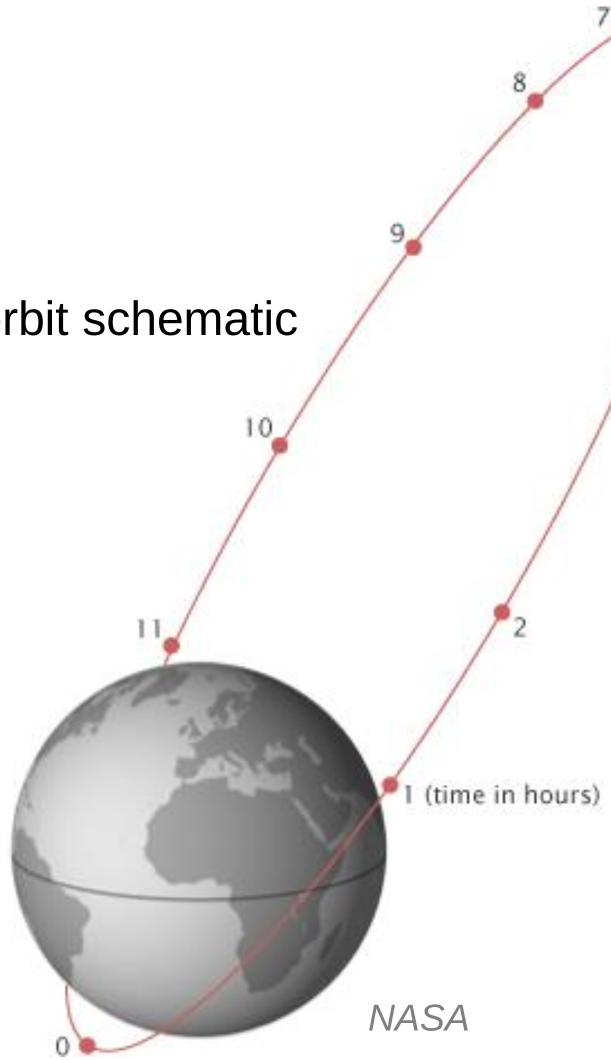
Example of a long duration flash which produces increased fire potential.
Video/permissions acquired from Marius Samoila

- Approximately 75% of all wildfires in the high latitudes are due to lightning. GLM and ISS-LIS do not reach high enough in latitude to cover the boreal forests.
- Optical brightness and duration measurements help provide information about how long a lightning flash is in contact with the ground. The duration of this contact determines if a fire will start.

Wildfire Partners: Alaska Fire Service, Bureau of Land Management, Alaska Fire Consortium, Bureau of Indian Affairs, USDA.
Other Weather Partners: National Weather Service, Alaska Aviation Weather Unit; **DoD Partners:** Ft. Greely Testbed

Backup/Additional Information

Molniya orbit schematic



Why not Molniya or Tundra?

- FOV and IFOV are not stable due to highly elliptical orbit
- Requires multiple instruments/satellites for continuous coverage of both hemispheres as well as coverage of diurnal cycle

Coauthors: R. J. Blakeslee[1], D. J. Cecil[1], H. J. Christian[2], P. N. Gatlin[1], S. J. Goodman[3], W. J. Koshak[1], W. A. Petersen[1], M. Quick[3], C. J. Schultz[1], and P. F. Tatum[1].

[1]NASA Marshall Space Flight Center, [2]University of Alabama in Huntsville, [3]National Oceanic and Atmospheric Administration (ret.)

Thanks!

Any Questions?