Airborne Lightning Observatory for FEGS and TGFs (ALOFT)

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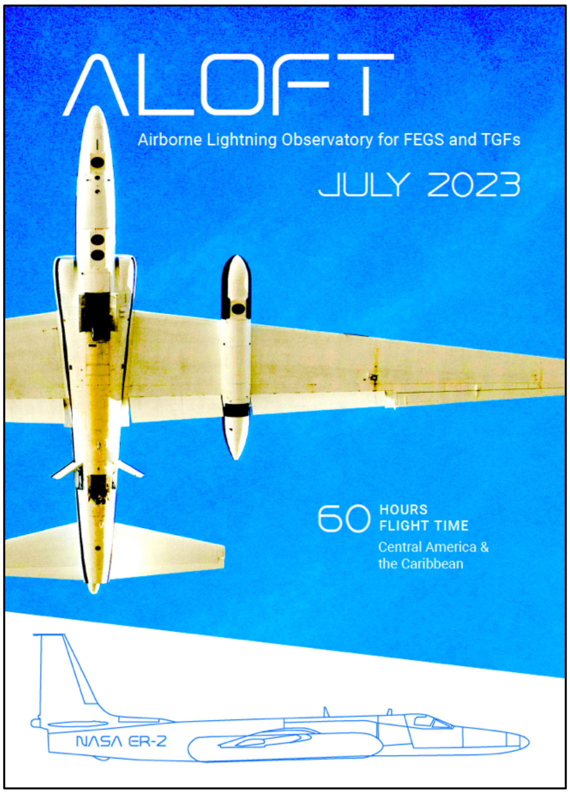
Executive Summary

The ALOFT campaign is a unique suborbital campaign to advance the science of high-energy radiation emissions from thunderstorms, validate existing spaceborne lightning mappers and evaluate design concepts for next-generation mappers, and study convection from a suborbital platform. ALOFT is a collaboration between NASA, the University of Bergen, and other institutions that will fly the ER-2 aircraft over tropical thunderstorms around the Gulf of Mexico, Central America, and the Caribbean. The payload will consist of lightning detectors, gamma-ray scintillators, and a mixture of passive and/or active microwave sensors. Supporting the flights will be a diverse ground-based network of lightning instruments spread across the region of interest.



Scientific Goals

Only 30 years ago it was discovered that a thunderstorm is the birthplace of the most energetic natural particle acceleration on Earth and **Terrestrial Gamma-ray Flashes (TGFs)** are the most explosive manifestation of such a process capable of delivering 10^{18} high-energy photons from thunderclouds to space in a few tens of microseconds. Lightning and TGFs are closely related but the details of this relationship are yet to be understood. **Gamma-ray glows** are another hard radiation phenomenon in thunderstorms. They have much lower flux than the TGFs, but since they probably extend thousands of square kilometers and last for tens of minutes or even hours, they can have a much larger effect on the atmosphere locally. Flying over the source thunderstorm and making high-resolution measurements of the gamma-rays, optical signals, and electric-field changes is key to solving the questions:

- *How and under what conditions are TGFs produced?*
- *How extended in space and time are gamma-ray glows?*

ALOFT is a follow-on study to expand in great detail lightning and gamma-ray observations collected during the GOES-R flight campaign in 2017. That campaign made ample observations of lightning in the mid-latitudes, and did observe gamma-ray glows, but failed to observe a TGF. This is likely because the spatiotemporal domain of the 2017 campaign was not optimized for detecting TGFs. ALOFT will optimize the spatiotemporal domain to detect TGFs from tropical thunderstorms during their seasonal maximum.

The full scientific goals of ALOFT are:

1. Observe TGFs in one of the most TGF-intense regions on the planet.
2. Observe gamma-ray glows in thunderstorms and their relation to TGFs.
3. Perform International Space Station Lightning Imaging Sensor (ISS LIS) and Geostationary Lightning Mapper (GLM) validation using improved suborbital instrumentation.
4. Evaluate new design concepts for next-generation spaceborne lightning mappers.
5. Make combined microwave and lightning measurements of tropical convection from a suborbital platform.

The ALOFT campaign will make measurements of TGFs and gamma-ray glows with unprecedented temporal and spatial resolution. Coordinated optical, gamma-ray, and electric field change measurements will provide the foundation needed to uncover the detailed physics that enables the production of high energy radiation from thunderstorms. Since gamma-ray glows require strong electric fields throughout a thunderstorm, it has been suggested that gamma-ray glows might be a prerequisite for producing TGFs. However, the two phenomena have never been observed simultaneously from space.

ALOFT also will enhance spaceborne lightning mapper performance validation and characterization in the tropics and oceanic regions where very little detailed ground validation is available. The year 2023 is likely the last full year for the ISS LIS mission, so target-of-opportunity underflights of LIS are needed to confirm mission performance near its end-of-life, complementing the early mission ER-2 observations made in 2017. In addition, GLM algorithms have been retuned multiple times since the GOES-R 2017 campaign, and additional GLM sensors have been launched. ALOFT will help confirm the new parameter settings and measurements using very similar optical observations.

Recent observations from the Atmosphere-Space Interactions Monitor (ASIM) instrument package on the ISS have documented surprisingly strong molecular emissions (streamer processes) at 337 nm along with the atomic emissions at 777.4 nm (leader/stroke), which have been traditionally used for lightning observations from space. This provides a unique opportunity for improving our understanding of lightning physics and lightning detection capabilities. *Observing lightning with improved multi-spectral optical sensors will enable significant improvements for next-generation lightning mappers (including potential GLM and ISS LIS follow-ons) in both their physical designs and data-processing algorithms.*

Finally, ALOFT will feature multiple active and passive microwave sensors. *These sensors will provide highly complementary observations of convective structure and evolution, which will provide valuable meteorological context for the lightning and gamma-ray observations.*

Instruments

ALOFT will use improved versions of the atmospheric electricity instruments used during the GOES-R validation campaign in 2017: Fly's Eye GLM Simulator (FEGS), Electric Field Change Meter (EFCM), Lightning Instrument Package (LIP), UIB-BGO (gamma rays), and iSTORM (gamma rays). These instruments will be upgraded, but will still all fit into the forward compartment of an ER-2 superpod (except for LIP). The gamma-ray instruments are being modified to accommodate the wide dynamic range required between the modest gamma-ray glow flux and the extremely high peak fluxes in TGFs. In addition, UIB-BGO will be able to provide realtime telemetry of gamma-ray observations, enabling detection of glows and subsequent reflight of glowing thunderstorms within minutes of their observation.

The FEGS instrument will include new spectral channels that will enable a look at strong lightning emission lines not observed by aircraft above cloud top since the mid-1980s. In addition, FEGS will feature additional improvements to nighttime sensitivity and reductions in stray-light contamination. LIP has recently been upgraded to improve its sensitivity and performance as well.

Because nearly all ALOFT instrumentation fits into half a superpod, while the remainder (LIP) fits around other ER-2 instruments, ALOFT can take advantage of instrumentation used in other recent campaigns. In particular, ALOFT will use Cloud Radar System (CRS), X-band Radar (EXRAD), Conically Scanning Sub-millimeter-wave Imaging Radiometer (CoSSIR), and the Advanced Microwave Precipitation Radiometer (AMPR), all of which recently completed the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) campaign, and have received NASA funding to participate in ALOFT. The complete package provides X- and W-band Doppler radar observations of thunderstorms, along with passive microwave observations in the 10-684 GHz range. These measurements are highly complementary to the lightning and gamma-ray observations and additionally are relevant to the forthcoming Atmosphere Observing System (AOS) mission.

Ground-based observations supporting ALOFT include a network of long-range low frequency (LF) sensors critical for characterizing TGF physics, as well as mixture of very high frequency (VHF), optical, and broadband electric field change sensors for mapping lightning.

Concept of Operations

The ALOFT domain is shown in Figure 1. The NASA ER-2 aircraft will be based at MacDill Air Force Base (AFB) in Tampa, Florida during July 2023. This location places the aircraft within range of most TGF hotspots over the Gulf of Mexico, Central America, and the Caribbean. A ground-based network of lightning sensors, particularly radio observations, provide overlapping coverage of this region as well. ALOFT will focus its flights on four basic regions: Florida/Bahamas, northern Central America near the Yucatan Peninsula, southern Central America including the islands of San Andres and Providencia off the Nicaraguan coast, and the northeastern Caribbean near Puerto Rico.

The science targets for ALOFT are primarily loosely organized but persistent groups of weak-to-moderate thunderstorms. These types of thunderstorms provide a good mix of lightning, TGF, and gamma-ray glow potential without compromising ER-2 safety. (ER-2 must fly at least 5000 feet above the tops of thunderstorms, which limits maximum targetable cloud-top height to ~18 km MSL.) These thunderstorm clusters allow for long-term loitering by the ER-2 using a mixture of linear, race track, and/or bowtie patterns that will sample a wide variety of thunderstorm structures and evolutionary states.

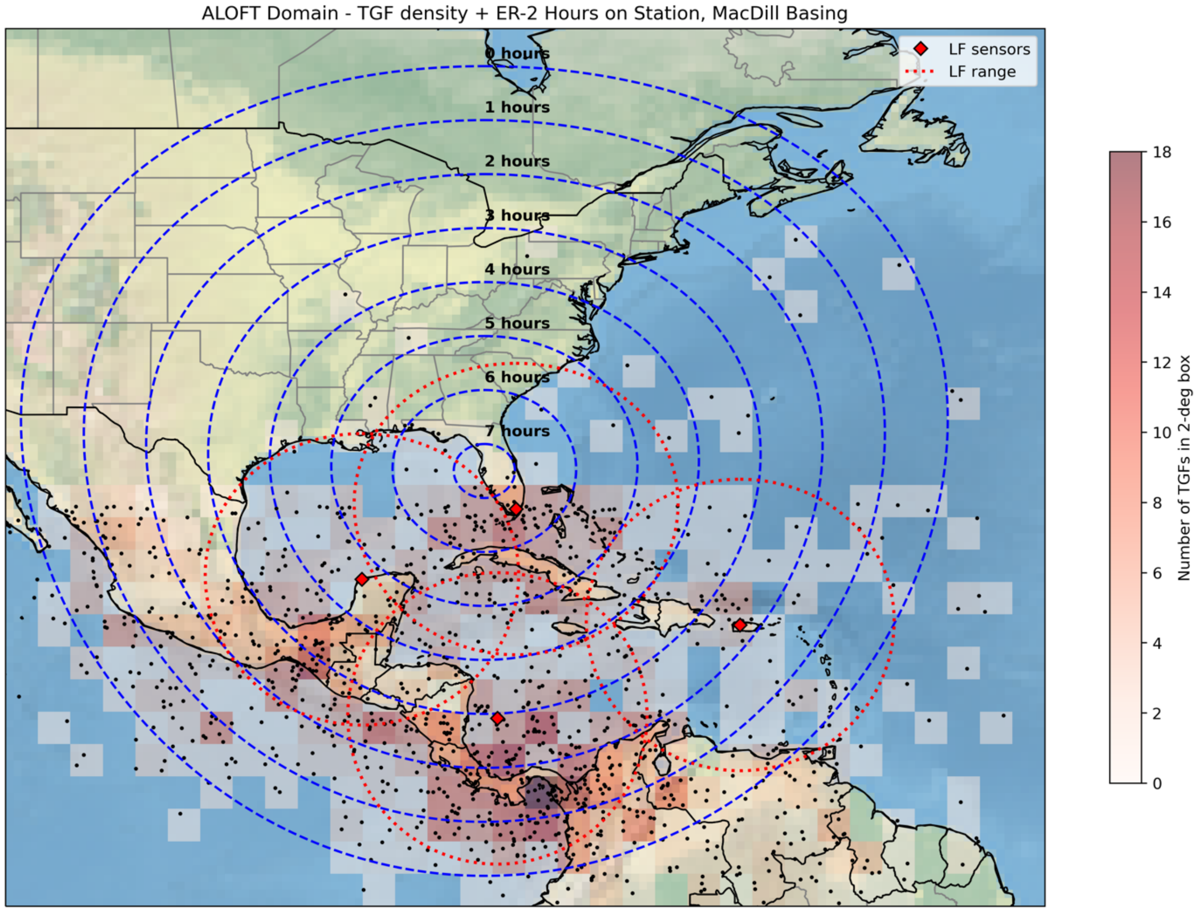


Figure 1: NASA ER-2 range rings (showing time on station) centered on MacDill AFB. Also shown are TGFs detected by Fermi Gamma-ray Burst Monitor (GBM) and ASIM during June-September (black dots and color contours), plus the locations and ranges of planned LF sensors in the region (additional LF sensors in the Southeast US not shown to reduce clutter).

Daily weather briefings will be provided the ALOFT forecast team. These will assess the potential for thunderstorms in the domain, as well as takeoff/landing weather for the ER-2. ALOFT mission scientists will then – in consultation with the ER-2 team, airborne instruments team, and ground sites team – make decisions about when and where to fly the ER-2 on a given day. A mission scorecard will be maintained and updated throughout the campaign to ensure and document overall success.

When a gamma-glowing thundercloud is encountered, based on realtime UIB-BGO telemetry updates, the ER-2 will be directed to immediately and continually refly the glowing thunderstorm in order to determine the glow's spatiotemporal extent.

ISS LIS overpasses will be monitored and assessed for their potential to synchronize with targetable thunderstorms in the ALOFT domain. Over Central America and much of the Gulf of Mexico, stereo observations with GLM-16 and GLM-18 are available, enabling vertically resolved measurements of lightning. Similar stereo observations between GLM-16 and Meteosat Third Generation Lightning Imager (MTG-LI) are available near Puerto Rico. Note that MTG-LI data are currently being validated, making underflights with FEGS and LIP potentially attractive to EUMETSAT.

ALOFT Personnel

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- Airborne Instrument Leadership: Eric Grove, Mason Quick, Christopher Schultz, Ian Adams, Rachael Kroodsma, Gerald Heymsfield, Hugh Christian, Randy Longenbaugh
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- Forecasting Team: Corey Amiot, Kelly Carmer, Austin Clark, Sebastian Harkema
- ER-2 Mission Management: Franzeska Becker, Samuel Choi

ALOFT Participating Institutions

- **University of Bergen (UIB)**
- **National Aeronautics and Space Administration (NASA)**
- Naval Research Laboratory (NRL)
- University of Alabama in Huntsville (UAH)
- Sandia National Laboratory (SNL)
- Duke University
- Georgia Institute of Technology
- University of Bath
- Universidad Nacional Autónoma de México (UNAM)
- Universitat Politècnica de Catalunya (UPC)