Assessing the Feasibility of a Spaceborne 3D Lightning Observing Concept

Patrick Gatlin1, Sonja Behnke2, Sarah Stough3, Randall Hopkins1, Harald Edens2, Timothy Lang1, Jackson Remington1,4, Mason Quick1, Phillip Bitzer3
1NASA Marshall Space Flight Center, 2Los Alamos National Laboratory, 3Univ. of Alabama in Huntsville, 4NASA Postdoctoral Program

Overview. Lightning is intimately tied to the thermodynamic, microphysical, and kinematic processes that modulate thunderstorm evolution. Mapping the three-dimensional (3-D) structure of electrical activity within a thundercloud has been highly valuable for studying these processes, but such capability is currently limited to regional networks like the Lightning Mapping Arrays (LMAs). Although satellite-based optical lightning mappers give excellent global coverage, they are unable to peer inside a cloud to map its electrical structure. To address this important observational gap, a new satellite concept called CubeSpark is being formulated. This study evaluates how CubeSpark can use a distributed network of orbiting lightning detectors to map the 3D structure of lightning activity with a resolution that enables new insights into thunderstorm processes and their interaction with the surrounding environment.

Orbital LMA Simulations

- Objective: Find optimal configuration of a six-satellite network of VHF lightning detectors that a TOA-based approach gives ≤ 2-km location accuracy from LEO
- Modified LMA simulation software package (Chmielewski & Bruning 2016) for TOA simulations with orbital network
- Remove line-of-site limitation on detection
- Add model of ionospheric dispersion
- Sensors are equally distributed along 2 orbital planes
- Vary network altitude, sensor spacing, and GPS timing uncertainty (0.5 ≤ σ ≤ 1.0µs)

Geographical Distribution of TOA-based Location Uncertainty for a LED Constellation of 6 VHF sensors

Horizontal Uncertainty (RMS) vs Spacing between adjacent sensors [km]

Vertical Uncertainty (RMS) vs Spacing between adjacent sensors [km]

Approaches for spaceborne 3-D geolocation of lightning

Single Satellite

- RF gives altitude; Optical gives latitude and longitude
- 3D requires detection of reflected pulses coincident with optical
- ~12-37% of FORTE VHF-optical dataset are TIPPs

Light & Jacobson 2002; Peterson 2022

3D location accuracy in single-satellite retrieval:
- Horizontal RMS error ~ resolution of optical (≤ 2 km)
- Vertical RMS error ~ 300 m (assumed σ = 0.5 µs)


Multi-Satellite

- Doesn’t rely on reflected pulse for 3D
- Role of optical in multi-satellite approach:
  - Constrain TOA solution (requires fewer VHF detections for 3D retrieval)
  - Train of satellites to observe evolution of storm for several minutes
  - Parallax-based pulse altitude
- 3D location solely from VHF time-of-arrival (TOA):
  - Horizontal RMS error ~ 500 m
  - Vertical RMS error ~ 1.2 km

Other CubeSpark-related projects

- Trade study looking at 3D observation approaches using two to five satellites with combined RF-optical
- Designing a new VHF lightning detector for a CubeSat platform
- Designing a bispectral lightning mapper to detect optically smaller and dimmer flashes
- Developing an Observing System Simulation Experiment (OSSE) for satellite-based lightning observations

Additional Info/Feedback

https://tinyurl.com/cubespark