Science & Technology Office

Modeling Methods for 3D Lightning Mapping from Space

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Current Spaceborne Lightning Mappers

Fast On-orbit Recording of Transient Events (FORTE)

- ✓ Optical imager
- ✓ RF sensor
- Pixel width ~10 km
- Time per frame ~2.5 ms

Lightning Imaging Sensor (LIS)

International Space Station (ISS)

Tropical Rainfall Measuring Mission (TRMM)

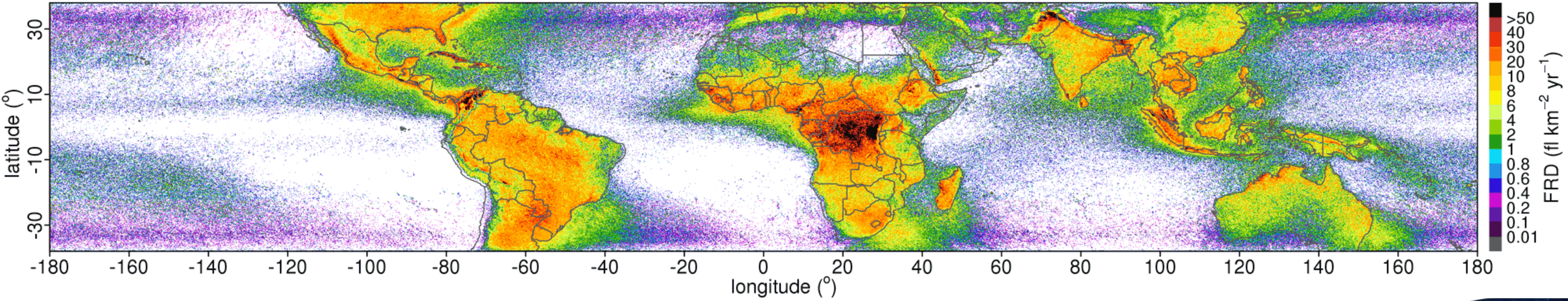
- ✓ Optical imager
- × RF sensor
- Pixel width ~10 km
- Time per frame ~2 ms

Geostationary Lightning Mapper (GLM)

Geostationary Operational Environmental Satellite (GOES-16)

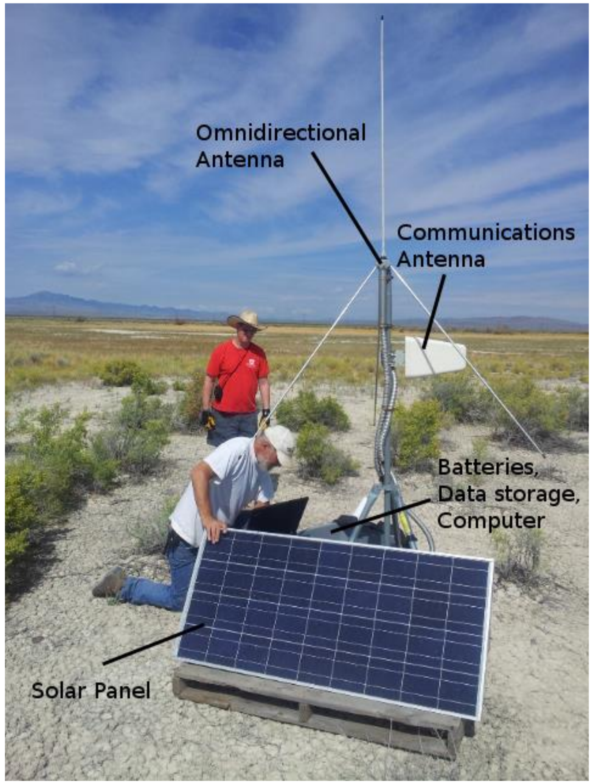
- ✓ Optical imager
- × RF sensor
- Pixel width 8-14 km
- Time per frame ~2 ms

LIS Very High Resolution Full Climatology (VHRFC) (1998-2013)

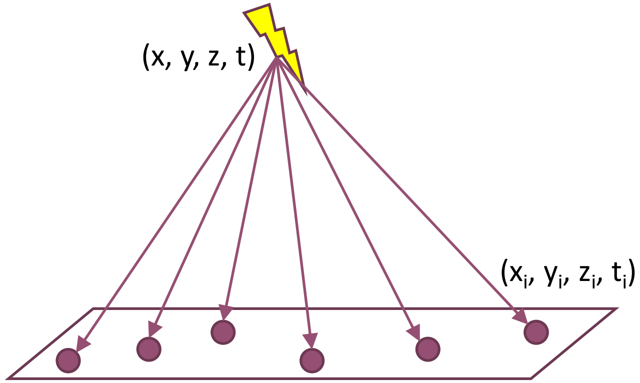


Ground-based Lightning Mapping Array (LMA)

- 6+ VHF Antennas centered on 66 MHz
- Time-of-arrival (TOA) analysis determines lightning activity position and time

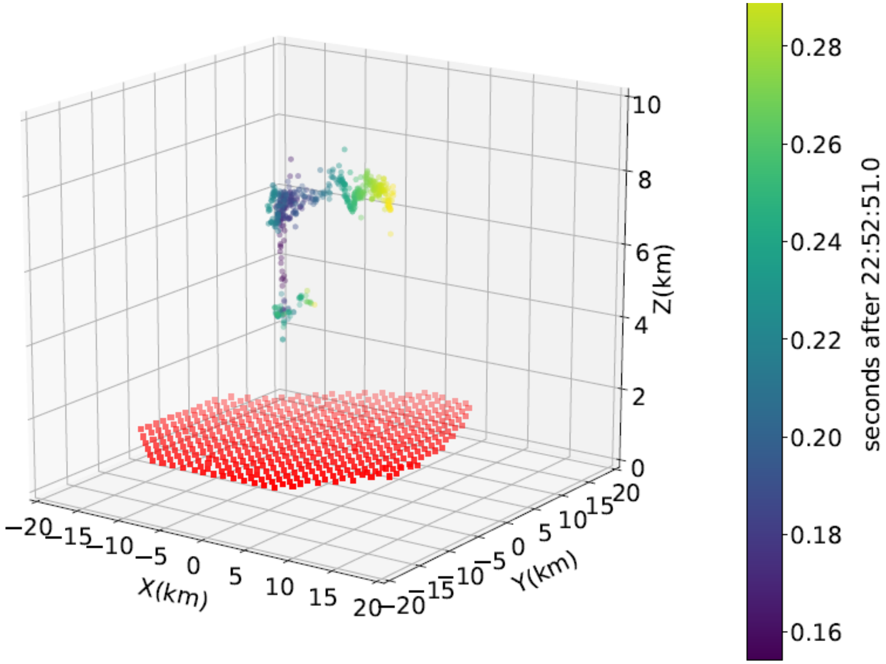


Remington, J. R. (2021)



- Horizontal accuracy 6-12 m
- Vertical accuracy 20-30 m
- Timing accuracy 40-50 ns
  - Typically a few data points per millisecond

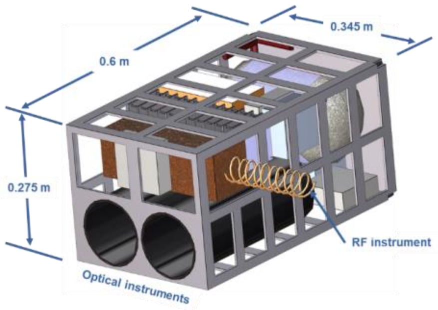
- Covers up to 1000s of km^2
- Preserves channel, flash, and cloud charge structure
- Not reliant on flash visibility
  - More sensitive to small flashes & daytime storms



Remington, J. R. (2021)

CubeSpark

- LMA in space!
- TOA lightning source location via RF signals
- Optical sensor up to 2000 FPS
  - 337 nm UV
  - 777 nm NIR
- <2 km spatial resolution
- Global coverage (<63°)



Los Alamos NATIONAL LABORATORY

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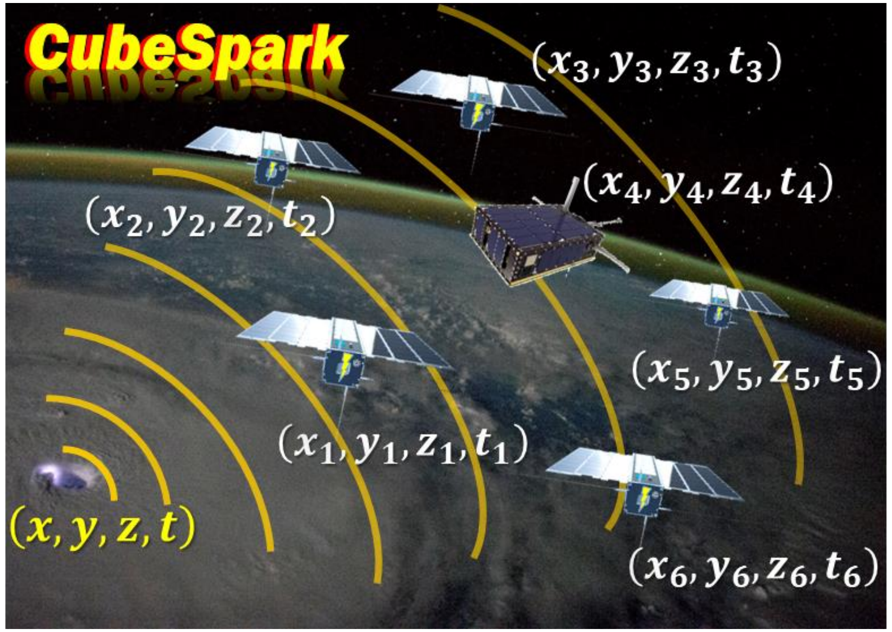
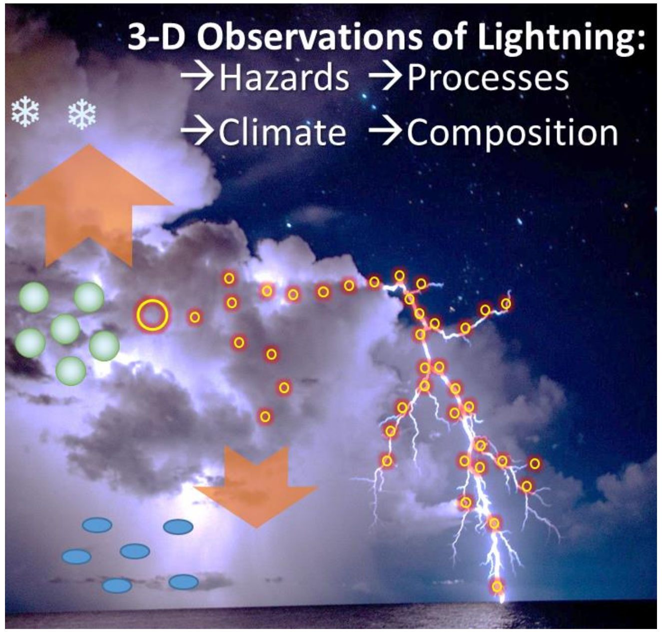
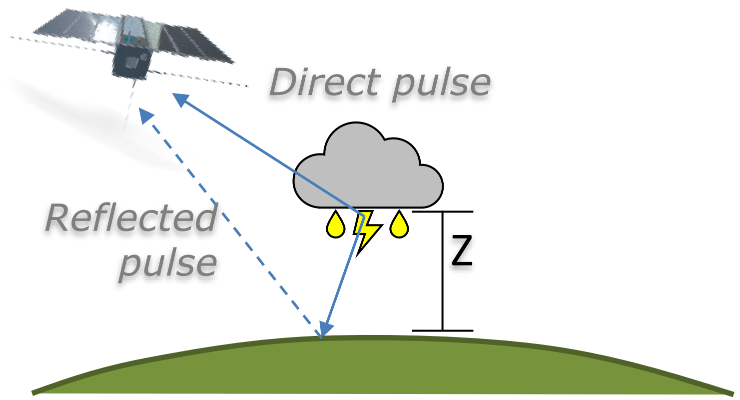
- Records lightning flashes and channel structure
  - Reveals cloud charge regions, channel length, and storm development
- More sensitive to small, dim flashes
- Help to identify NOx production, updraft strength, severe storm development, etc.

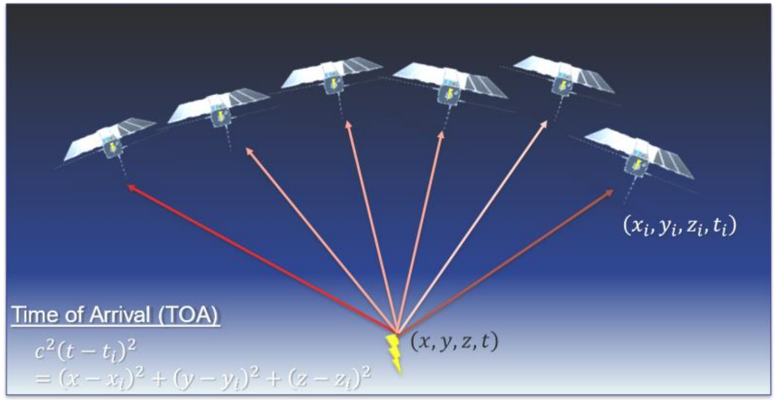




Science/Application Benefitted	Flash Altitude	Charge Structure	Channel Length
Severe Weather	✓	✓	
Precipitation Science		✓	
LNOx (Atmos. Comp & Climate)	✓		✓
Optical lightning detection (Weather forecasting & Climate)	✓		
Wildfire/Winter Weather	✓	✓	

Single-satellite Approach vs. Multi-satellite Approach



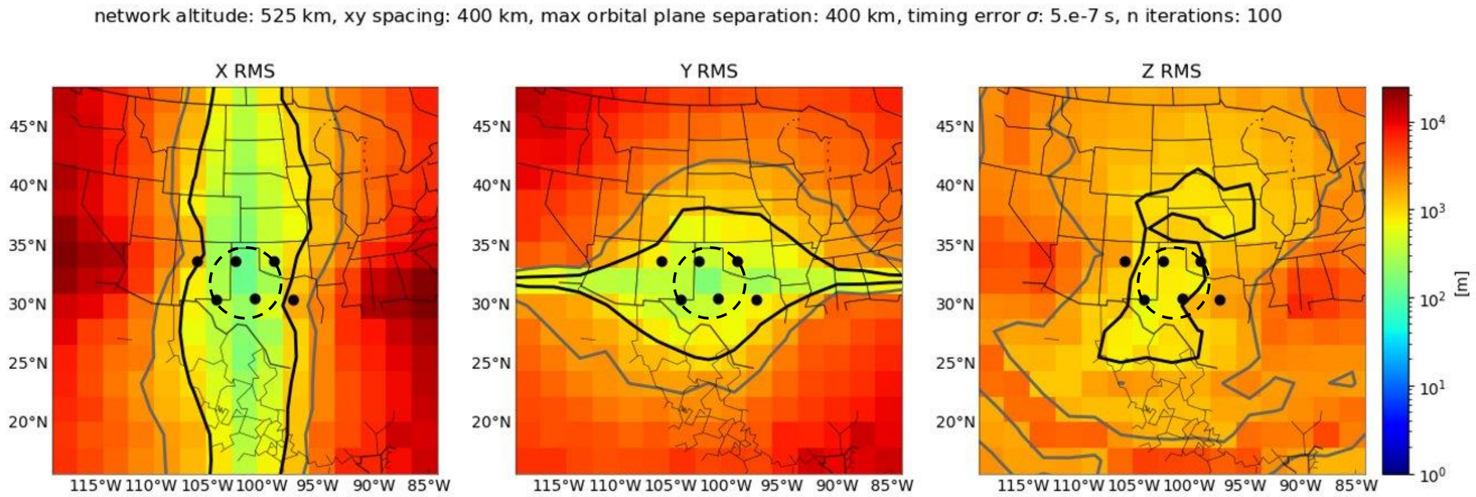


- Optical imager supplies a flash's horizontal position
- RF sensor records both direct and reflected pulses from each source
  - 4 measurements -> 4 coordinates
- ~12-37% of FORTE VHF+optical dataset are TIPPs (Light & Jacobson 2002; Peterson 2022)
- Same method as FORTE altitude measurements with higher resolution
  - Horizontal RMS error ~ resolution of optical (≤2 km)
  - Vertical RMS error ~ 300 m
  - Timing error assumed to be 0.5 µs

- Parallax-based pulse altitude
  - Doesn't rely on reflected pulse for 3D
  - Can resolve 3D location solely from TOA
  - Optical imager can constrain TOA solution (requires fewer VHF detections for 3D retrieval)
  - Horizontal RMS error ~ 500 m
  - Vertical RMS error ~ 1-2 km
- Train of satellites using reflected TIPP method
  - Can observe evolution of storm for several minutes with better vertical resolution

CubeSpark/LMA Simulation

- LMA simulation tool adapted for orbiting "stations"
- Accounting for ionospheric dispersion of VHF signals
- <500m RMS horizontal error
- <2000m RMS vertical error

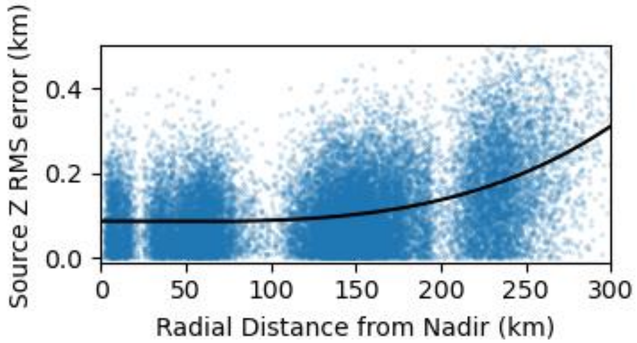


Credit: Sarah Stough

Single-satellite Approach vs. Multi-satellite Approach

Single-satellite Approach

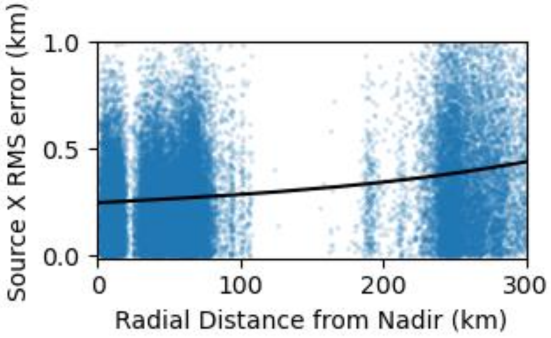
- Relies on TIPP detection
- 1200m average horizontal error
  - Based on optical pixel width of 2000m
- 150m average vertical error!

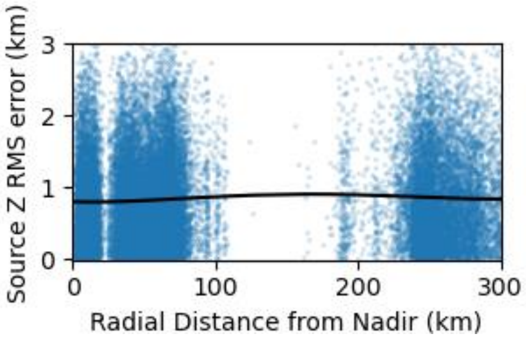


(28,000 VHF sources)

Multi-satellite Approach

- ~325m average horizontal error
- ~1000m average vertical error

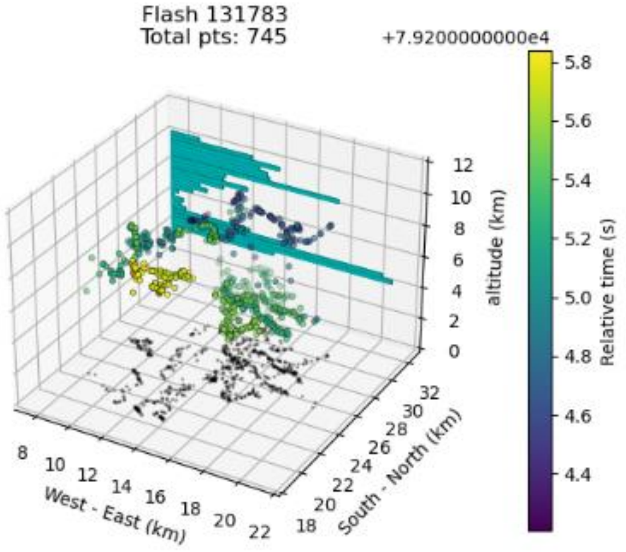




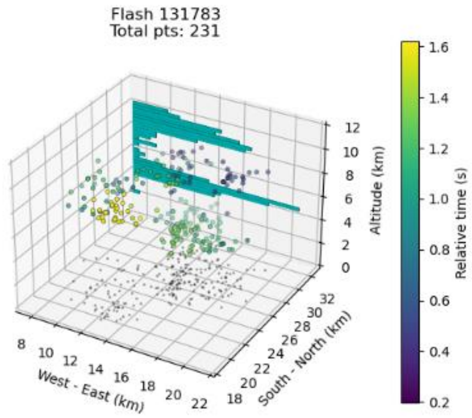
(34,000 VHF sources)

CubeSpark/LMA Simulations – Flash Structure

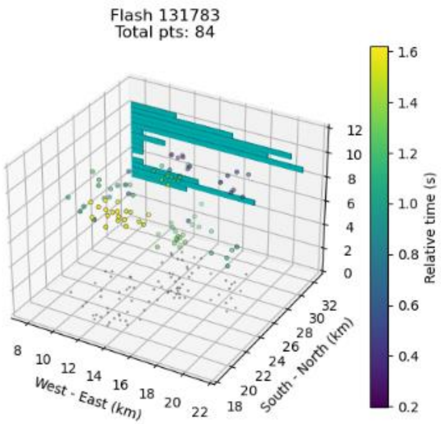
- Large single lightning flash recorded by North Alabama LMA
  - 745 VHF sources over 1.5 seconds
- Clear channel development
- Distinct charge regions



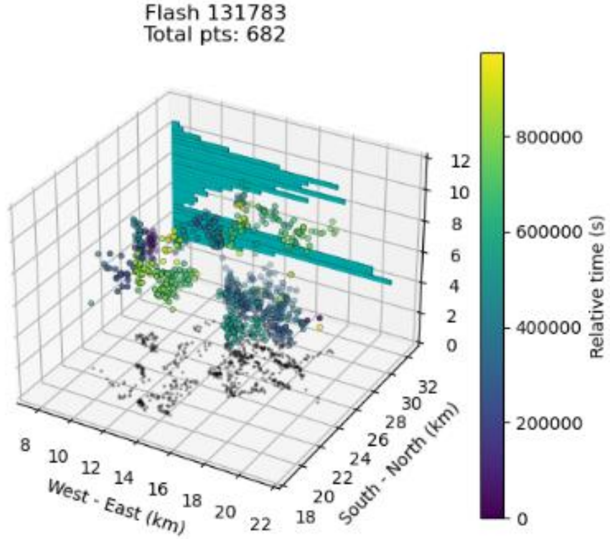
Single-satellite Approach vs. Multi-satellite Approach



(37% of VHF sources produced TIPPs)
(Light & Jacobson 2002)



(12% of VHF sources produced TIPPs)
(Peterson 2022)



Summary

- **High-resolution 3D lightning mapping** provides valuable information for:
  - climate and atmospheric sciences
  - more accurate traditional lightning studies
  - identifying severe weather

- **CubeSpark** is intended to improve:
  - **resolution** of existing lightning mapping tools by up to an order of magnitude
  - **sensitivity** to small/dim flashes
  - **uptime and coverage** of dual optical/RF observations

- Possible configurations:
  - **Multi-satellite** approach using RF signals for time-of-arrival analysis
    - **<500m** horizontal uncertainty, **<2000m** vertical uncertainty
  - **Single-satellite** approach relying on TIPP detection
    - **<2000m** horizontal uncertainty, **<500m** vertical uncertainty
  - Some combination of both?

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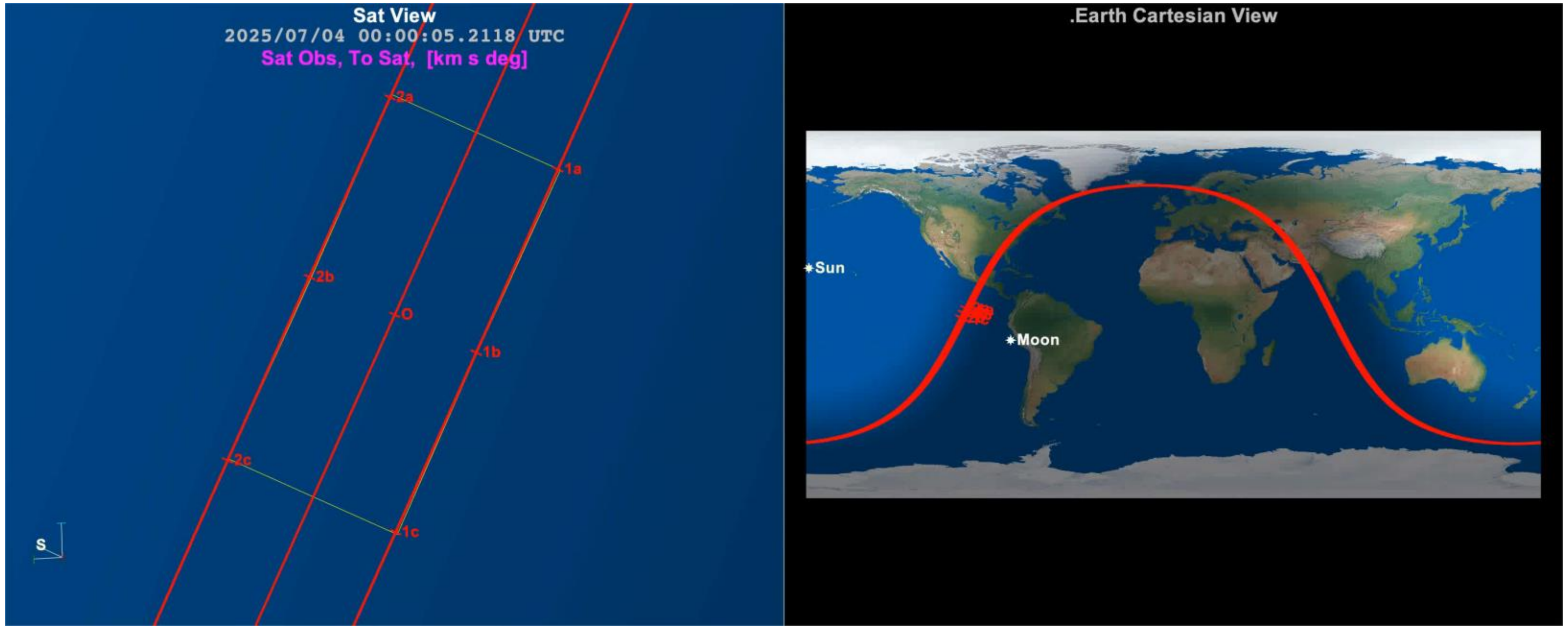
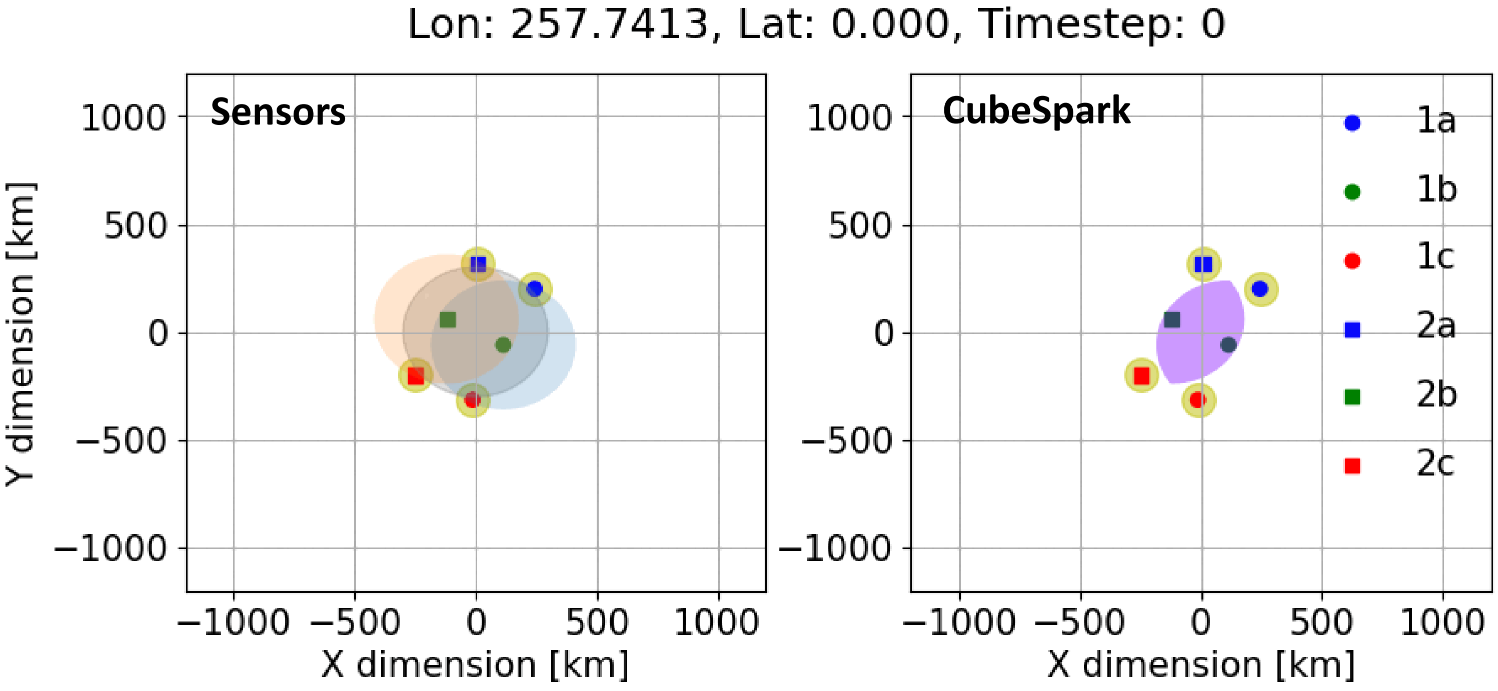
Supplemental Slides

CubeSpark Orbit

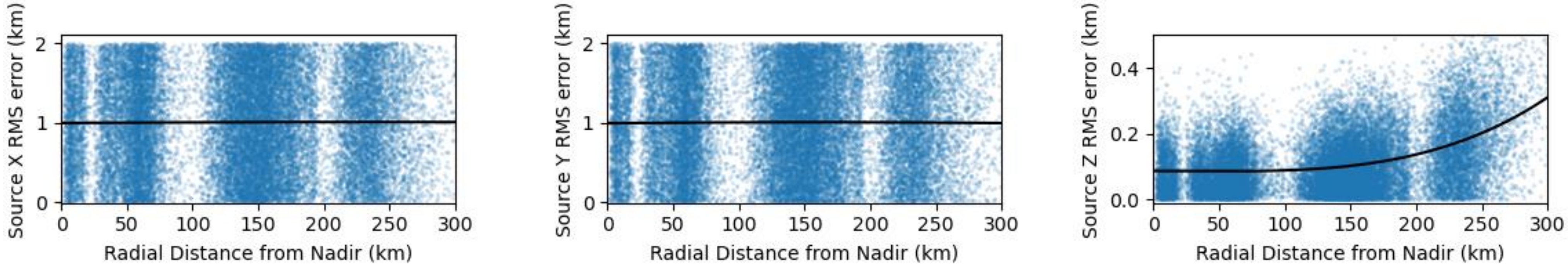
- Low Earth Orbit (~525 km)
- 300-400 km satellite spacing
- 63° inclination



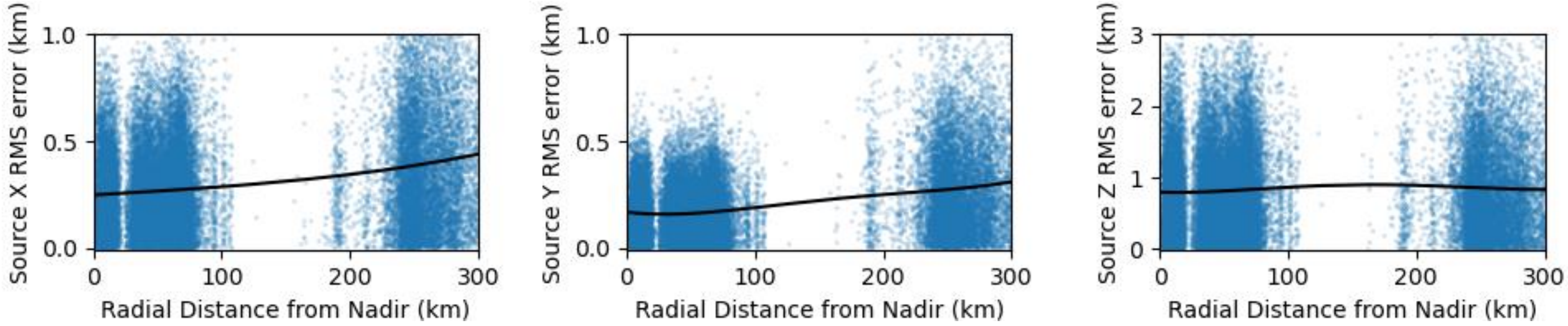


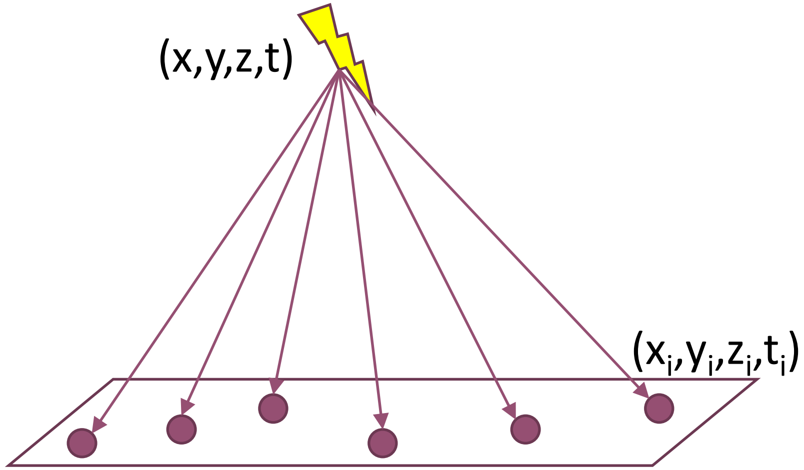
CubeSpark Simulations

- Single-satellite approach



- Multi-satellite approach

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