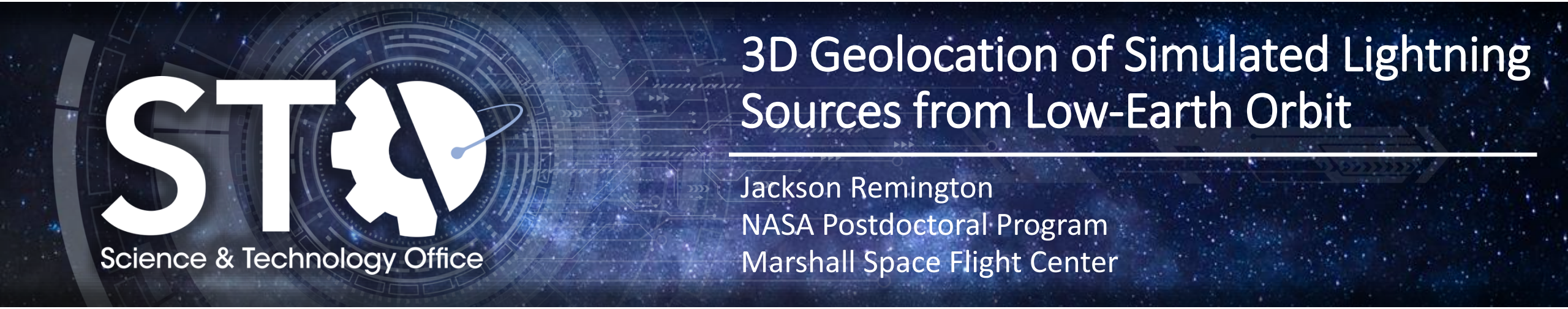
National Aeronautics and Space Administration



3D Geolocation of Simulated Lightning Sources from Low-Earth Orbit

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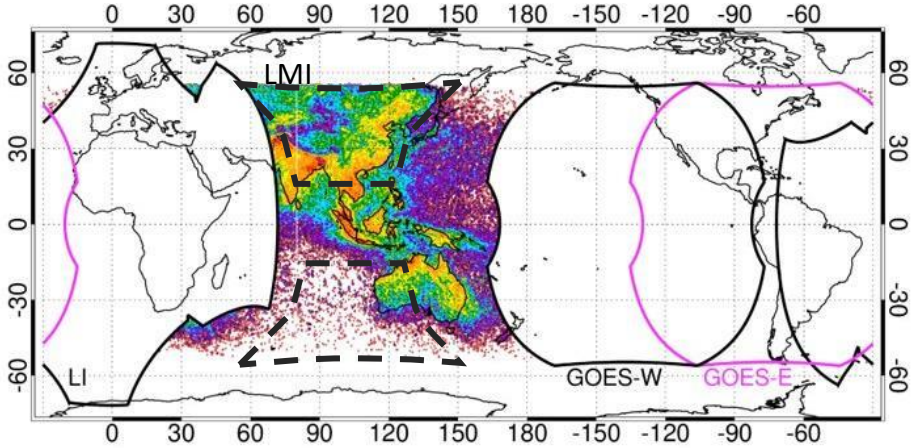
Orbital Lightning Mapping

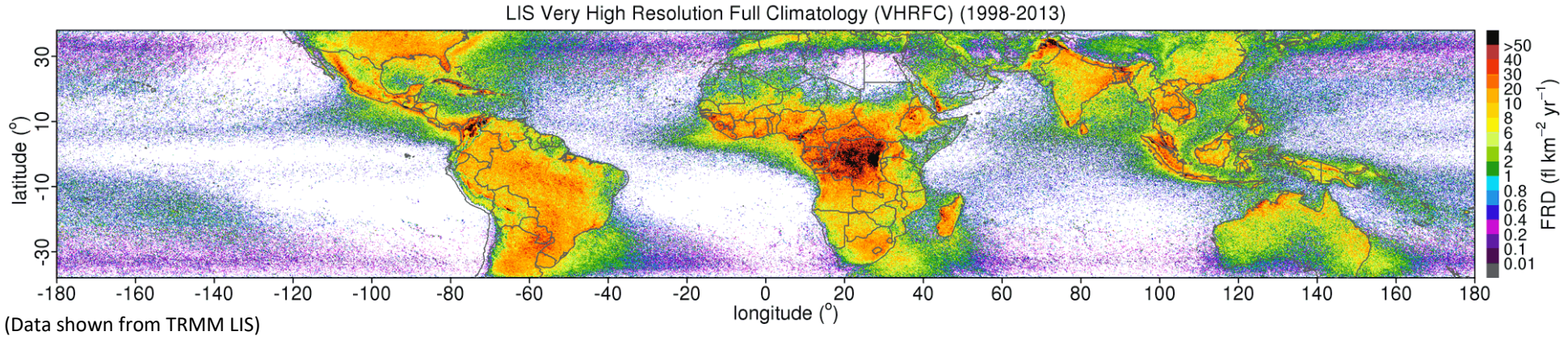
- Optical observation
  - From geostationary or low-Earth orbit
  - Near-infrared (777 nm): hot leader processes
  - Ultraviolet (337 nm): streamer-based processes

- Radio frequency (RF) detection
  - Very high frequency (30-300 MHz)
  - Fast On-orbit Recording of Transient Events (FORTE)
  - Ground-based Lightning Mapping Array (LMA)

Coverage of GEO lightning mappers (2023)



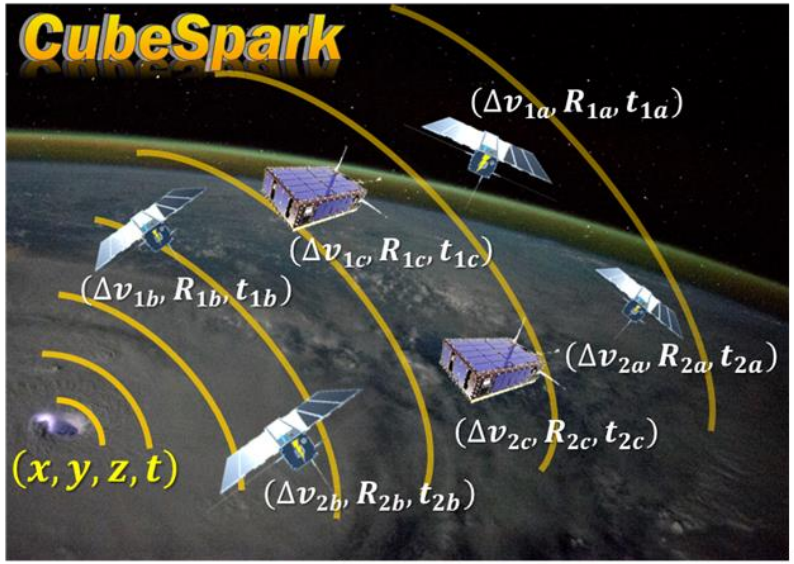
Lightning Imaging Sensor (ISS LIS): 2017-2023



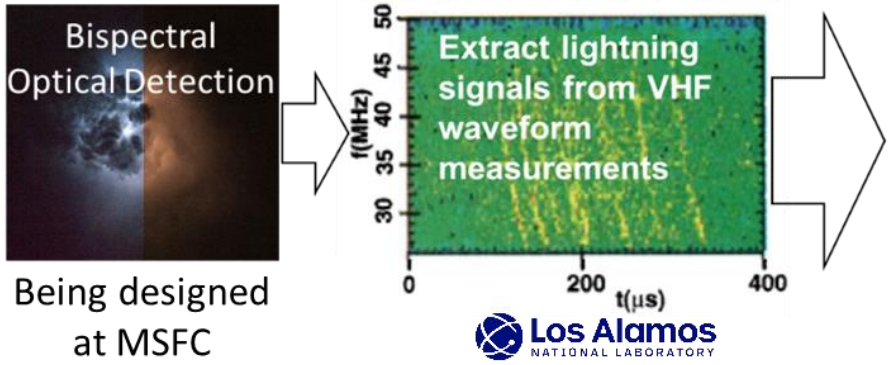
(Data shown from TRMM LIS)

CubeSpark: A Next-Generation 3D Lightning Mapping Concept

- A constellation of small satellites in low-Earth orbit
  - VHF radio measurements to map structures of lightning and thunderstorm charge regions
  - Bispectral, high-resolution optical measurements to further enhance lightning detection and analysis



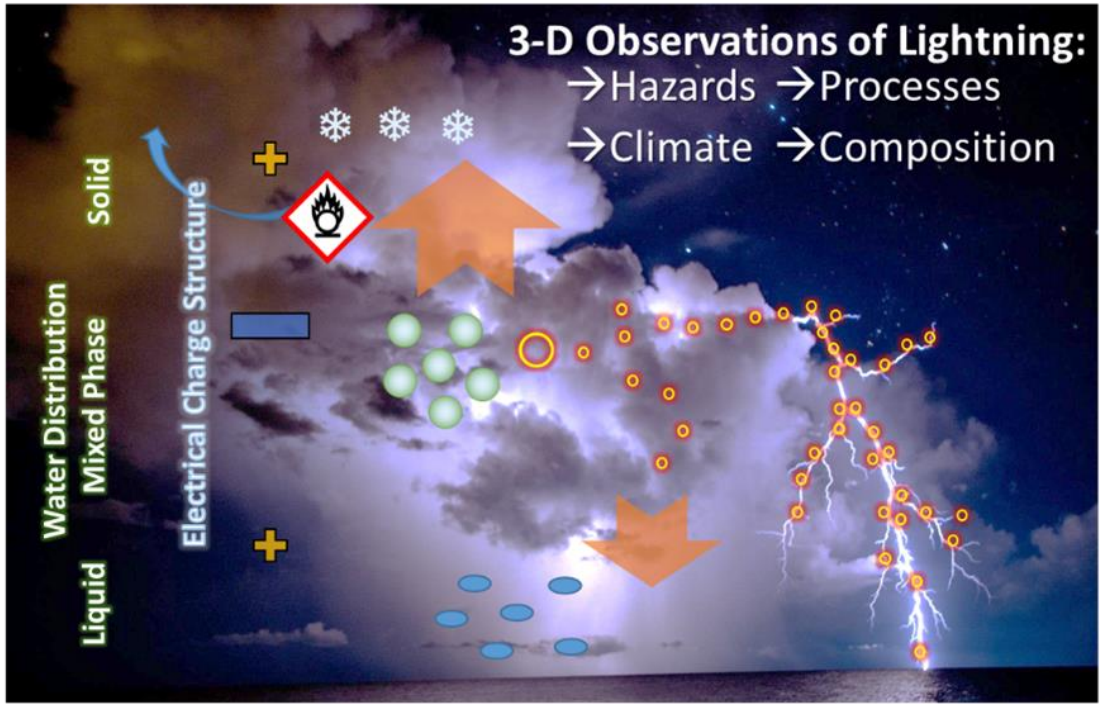
Measurement Concept



Being designed at MSFC

Los Alamos NATIONAL LABORATORY

Enabled Science and Applications



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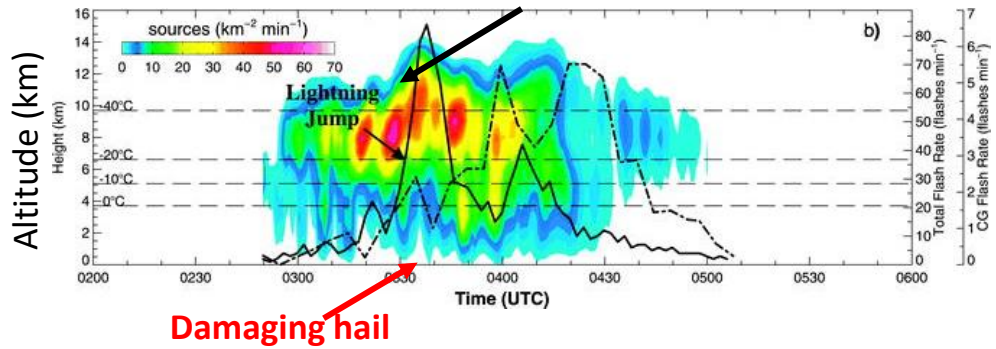
Vertical Observation Empowers Scientific Application

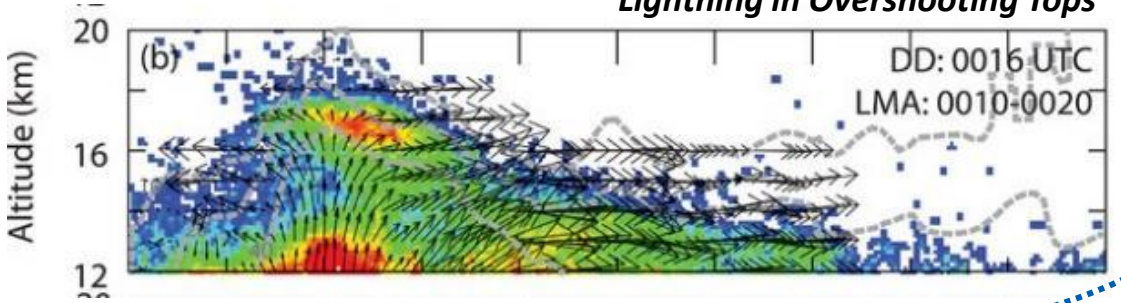
Vertical surge of VHF lightning source density

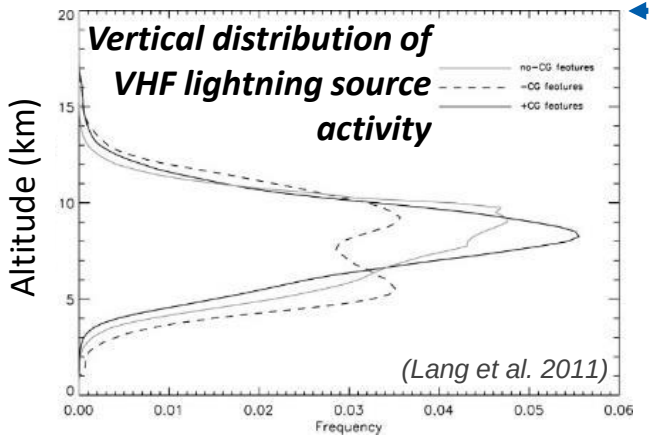
(Gatlin & Goodman 2010)

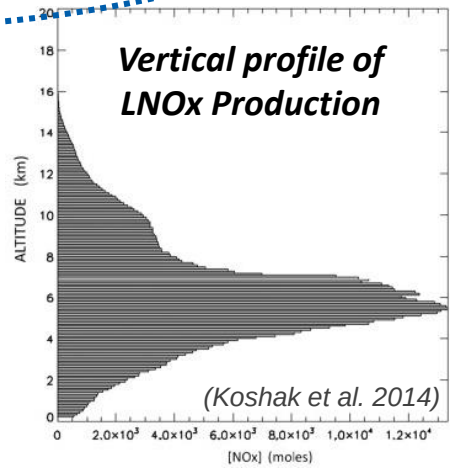


(Calhoun et al. 2013)

Lightning in Overshooting Tops



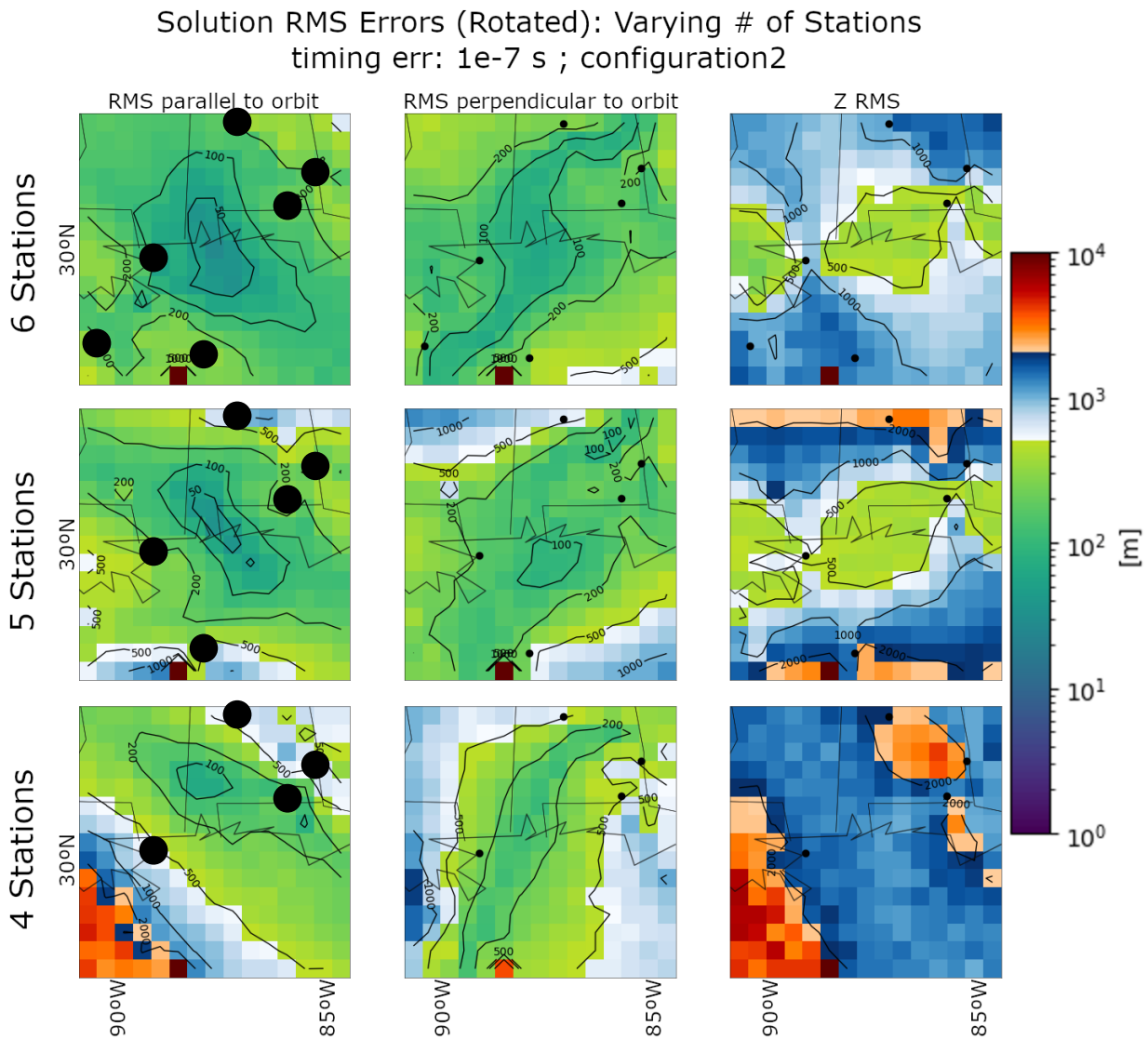




- **<2 km resolution**
  - Identify severe storm intensification
  - Determine convective properties
  - Infer cloud charge structure
- **<1 km resolution**
  - Map channel structure
  - Model distribution of lightning-produced nitrous oxide (LNOx)

These studies are enabled by 3D lightning observations, limited to regional, ground-based networks (LMA, etc.)

VHF-Based Time of Arrival (TOA)

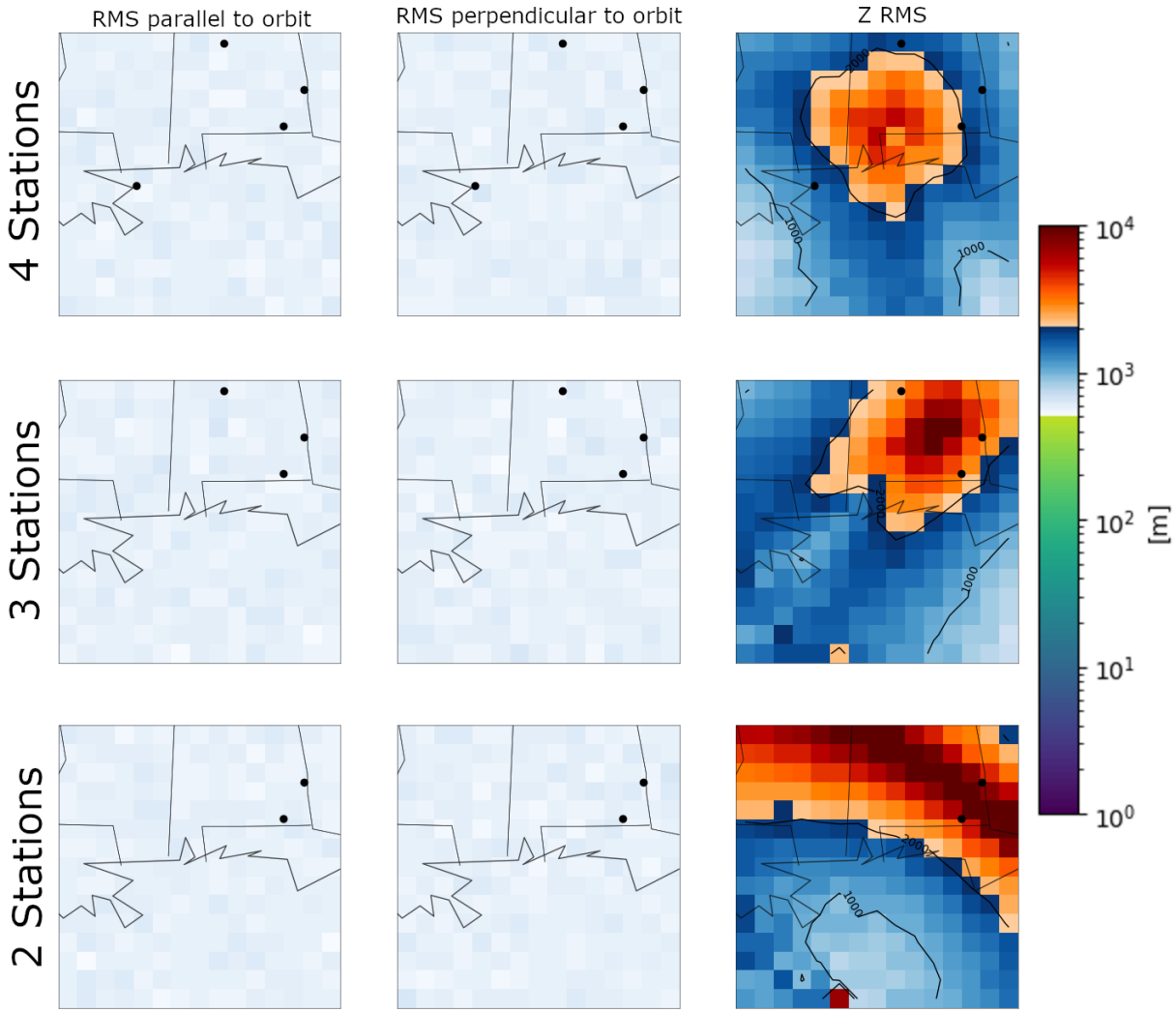


Test location at mid-latitudes (30.2° N, 92.3° W)

RMS errors in x', y', z :

- 6 satellites:
  - 160 m, 210 m, **850 m**
  - ~60% coverage with 3D resolution <1 km
- 5 satellites
  - 290 m, 330 m, **1100 m**
  - ~44% coverage with 3D resolution <1 km
- 4 satellites
  - 760 m, 500 m, **2000 m**
  - 0% coverage with 3D resolution <1 km
  - ~75% coverage with 3D resolution <2 km

Optically-Constrained TOA



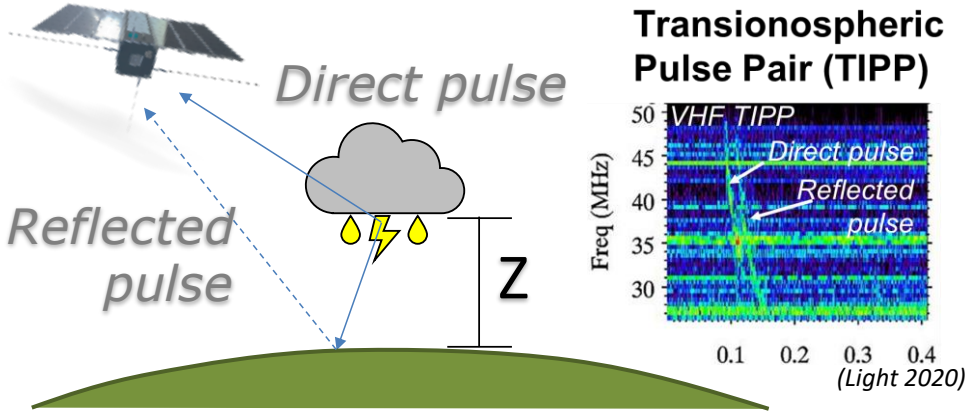
Test location at mid-latitudes (30.2° N, 92.3° W)

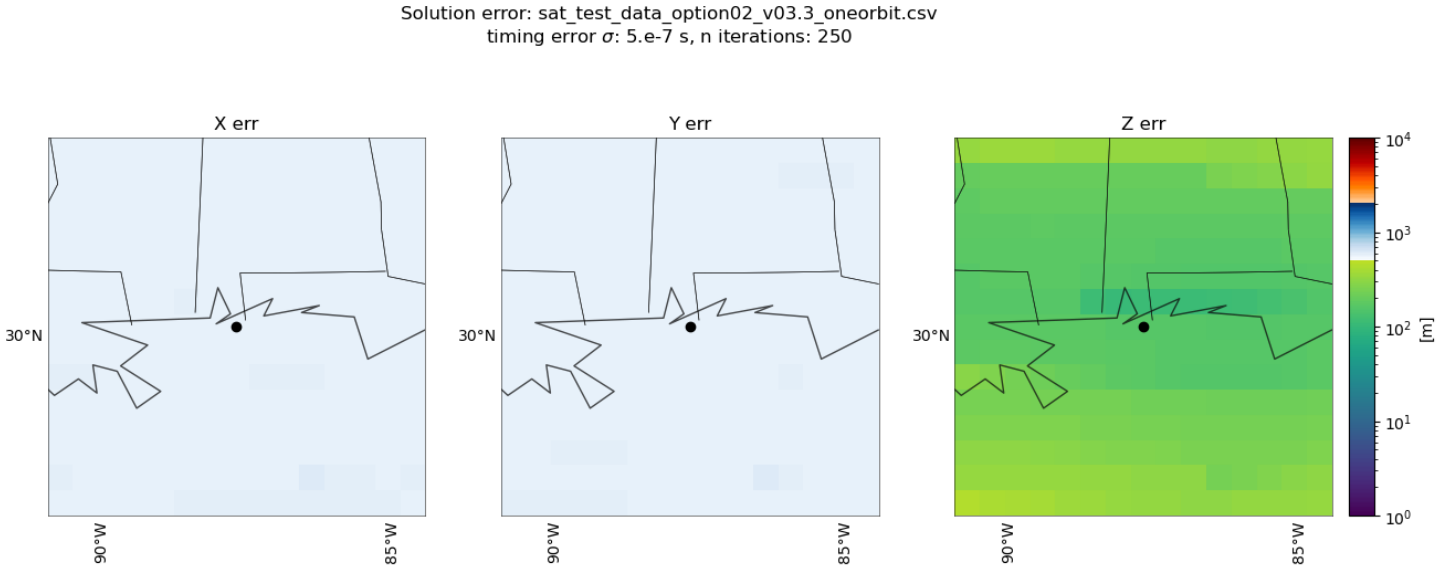
RMS errors in x', y', z :

- 4 satellites:
  - 580 m, 580 m, **1700 m**
  - ~13% coverage with 3D resolution <1 km
- 3 satellites
  - 580 m, 580 m, **1900 m**
  - ~10% coverage with 3D resolution <1 km
- 2 satellites
  - 580 m, 580 m, **3800 m**
  - ~10% coverage with 3D resolution <1 km

Single-Satellite Reflected Pulse Method

- Requires optical constraint and reflected VHF emission
  - 12-32% of VHF sources
  - Horizontal position given by optical imager
  - Altitude and time given by direct and reflected pulses



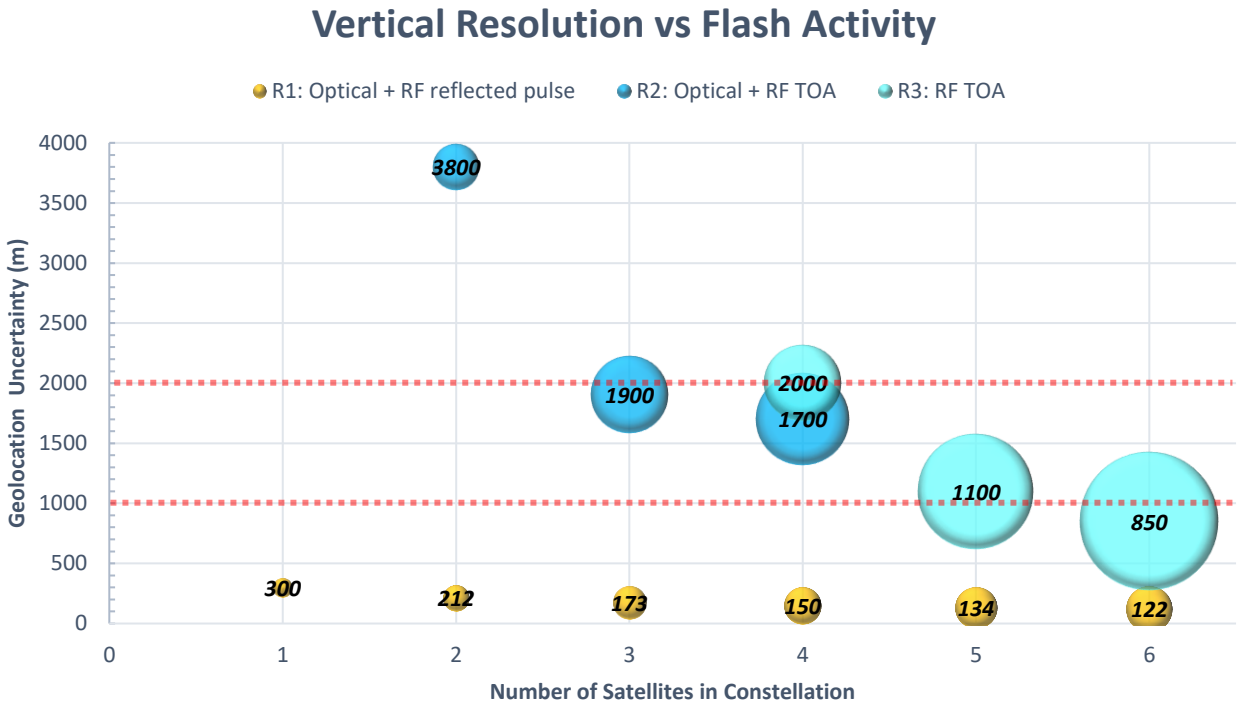


RMS errors in x, y, z :

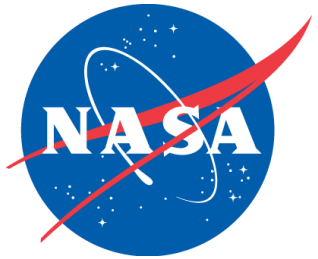
- 580 m, 580 m, **300 m**
- ~100% coverage with 3D resolution <1 km

Summary of Results

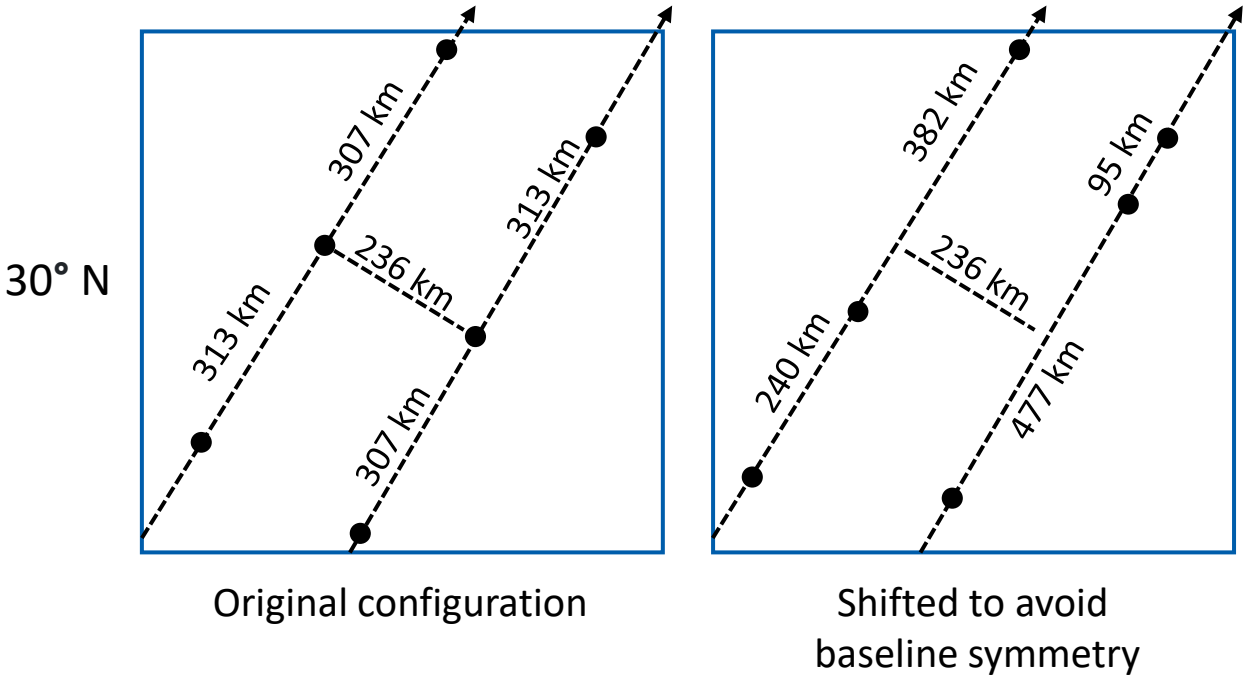
- High resolution 3D lightning geolocation would represent a significant advancement in fields beyond lightning from meteorology to climate modeling.
- Storm charge layers can be inferred with vertical accuracy <2 km, lightning structure may be resolved with accuracy <1 km
  - (with caveats of detection efficiency)
- Using **pure-VHF** TOA, expected vertical accuracy is:
  - **850 m using 6 satellites**
  - **1,100 m using 5 satellites**
  - <5 satellites unreliable
- Using **optically-constrained** TOA, expected vertical accuracy is:
  - **1,700 m using 4 satellites**
  - **1,900 m using 3 satellites**
  - <3 satellites unreliable



- Size represents relative number of well-resolved sources (approx.)

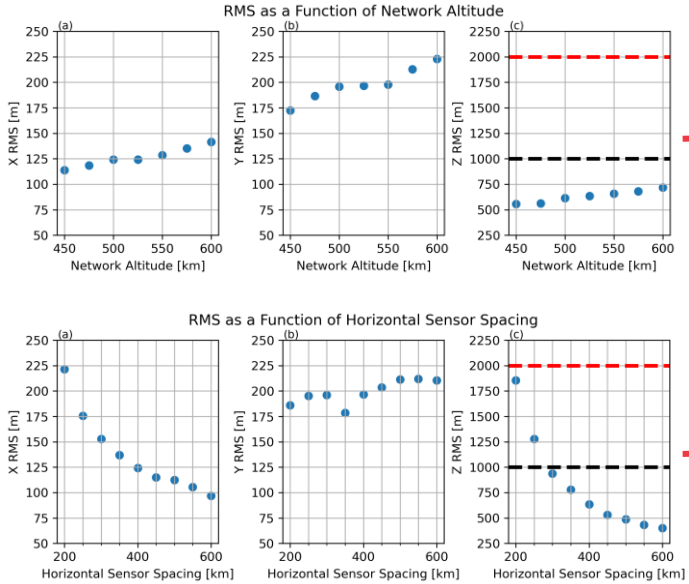

NASA

Supplementary - CubeSpark Constellation Design



Original configuration

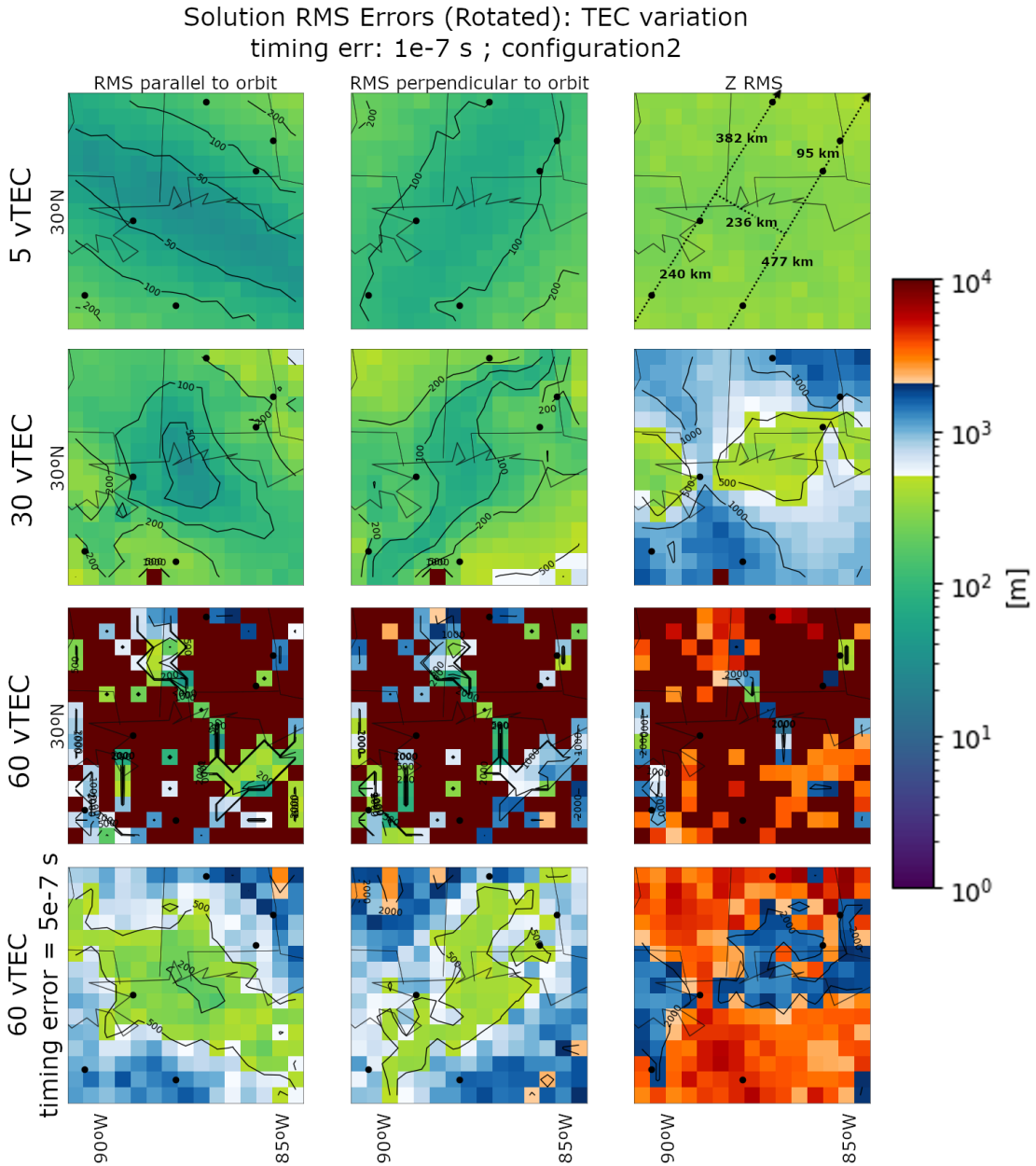
Shifted to avoid baseline symmetry



Altitude:
525 km

Average separation:
300 km

Supplementary - Ionospheric Total Electron Content (TEC) Variation



RMS errors in x', y', z :

- 5 TECU:
  - 85 m, 110 m, **290 m**
  - 100% coverage with 3D resolution <1 km
- 30 TECU
  - 160 m, 210 m, **850 m**
  - ~60% coverage with 3D resolution <1 km
- 60 TECU
  - Poor algorithm convergence rates
- 60 TECU (relaxed timing)
  - 720 m, 870 m, **2700 m**
  - 0% coverage with 3D resolution <1 km
  - ~30% coverage with 3D resolution <2 km