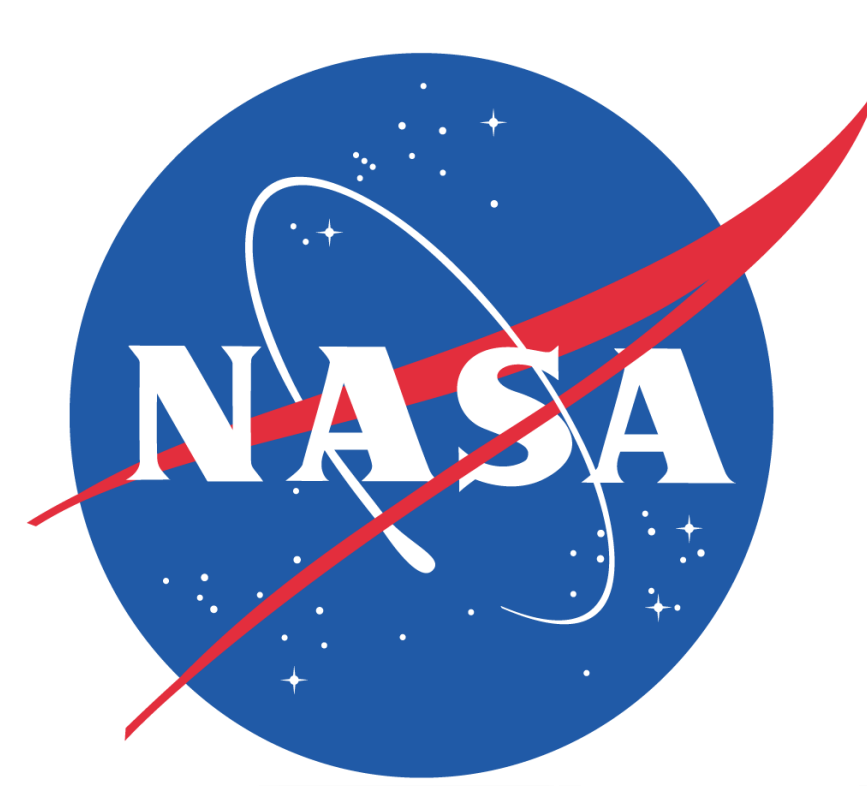




Modeling Methods for 3D Lightning Mapping from Space

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Motivation

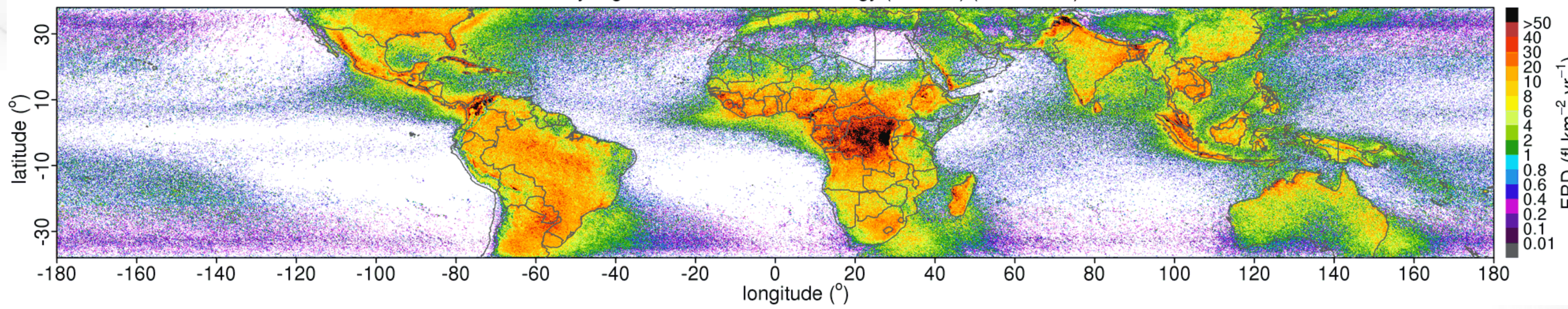
Current lightning mapping focuses on global lightning flash rates and locations for applications in climatology, meteorology, and atmospheric science.

The concept of CubeSpark as a next generation lightning mapper is to improve on the 3D accuracy of these observations in order to map internal flash structures. This new capability will have unprecedented benefits in a range of fields that rely on lightning data. **Its primary goals are:**

- 1-2 km spatial resolution of individual VHF sources
- Colocated RF sensor and combined UV/NIR optical imager

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	✓	✓	

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



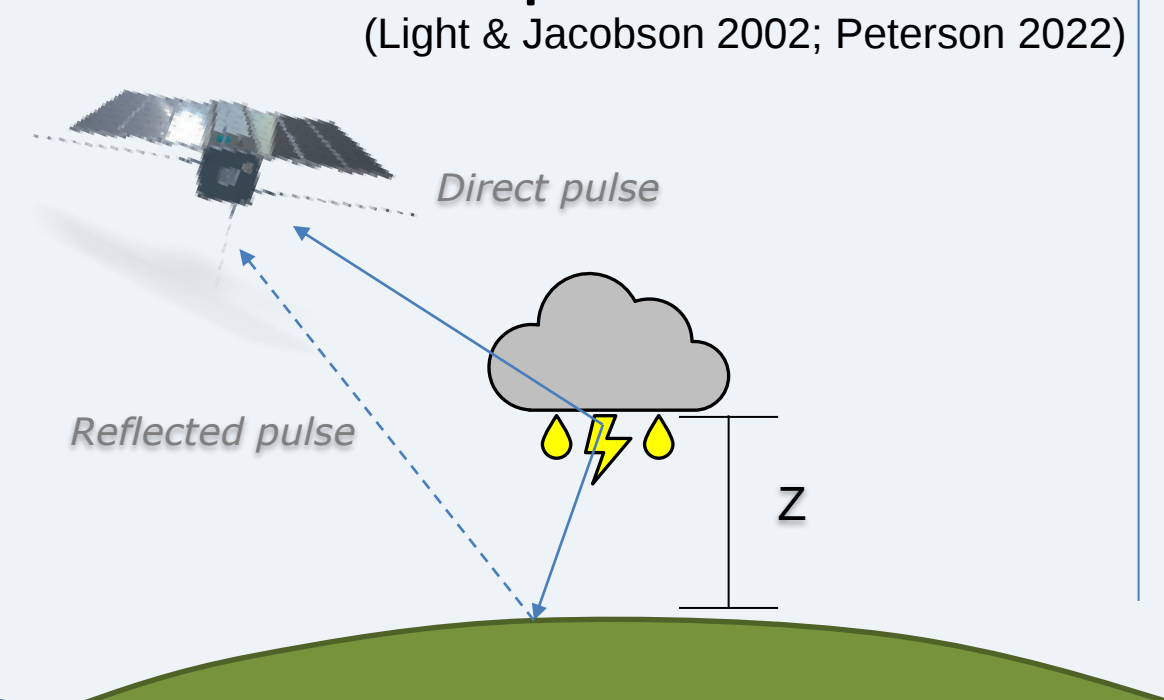
CubeSpark 3D Mapping Methods

As with any mission, CubeSpark needs to balance cost and simplicity with data integrity and applicability. In this pursuit, the number of satellites required to meet the mission goals is being explored, each with different possible methods of locating lightning sources

1 satellite	2 satellites	3 satellites	4 satellites	5 satellites	6 satellites
TIPP solution	TIPP solution (train)	TIPP solution (train)	TIPP solution (train)	TIPP solution (train)	TIPP solution (train)
	TIPP solution (averaged)	TIPP solution (averaged)			
	Constrained TOA + optical (0 DoF)	Constrained TOA + optical (1 DoF)	Constrained TOA + optical (2 DoF)		
			Pure TOA method (0 DoF)	Pure TOA method (1 DoF)	Pure TOA method (2 DoF)

Trans-ionospheric pulse pairs (TIPP):

- Uses Earth-reflected pulse to calculate source altitude
- Horizontal position constrained by optical imager
- 12-32% of sources produce TIPPs (Light & Jacobson 2002; Peterson 2022)

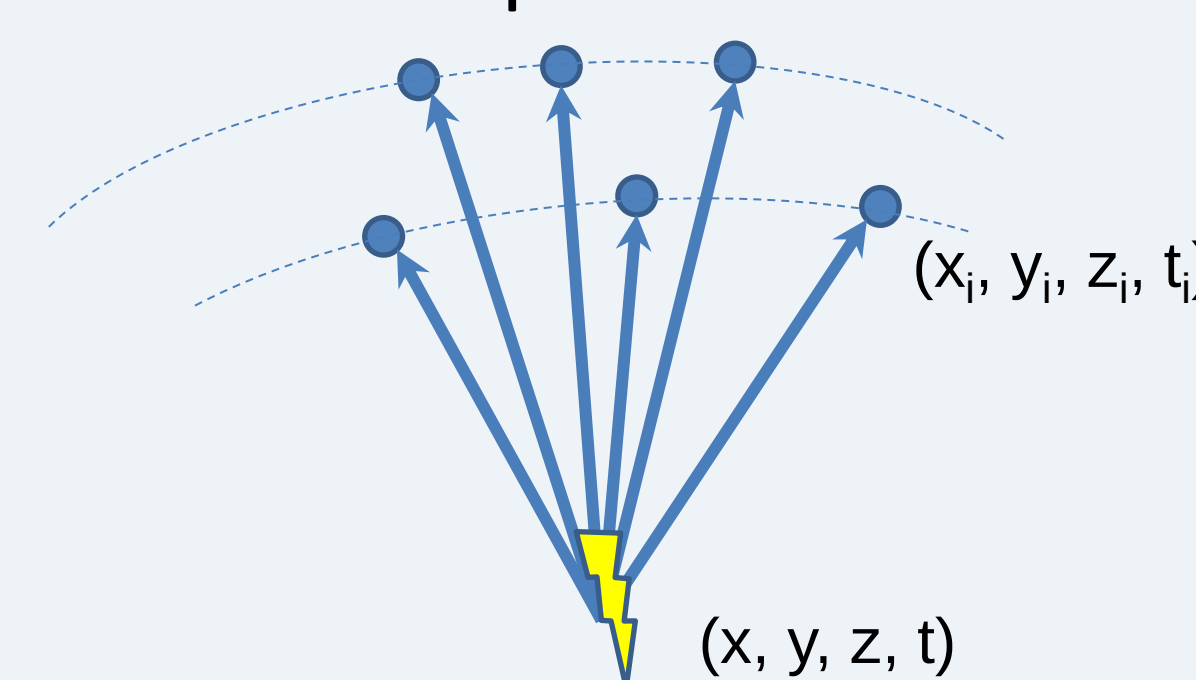


Constrained time-of-arrival (TOA):

- Horizontal position constrained by optical imager
- Doesn't rely on TIPP detection
- Time and altitude overdetermined by arrival time

Pure TOA method:

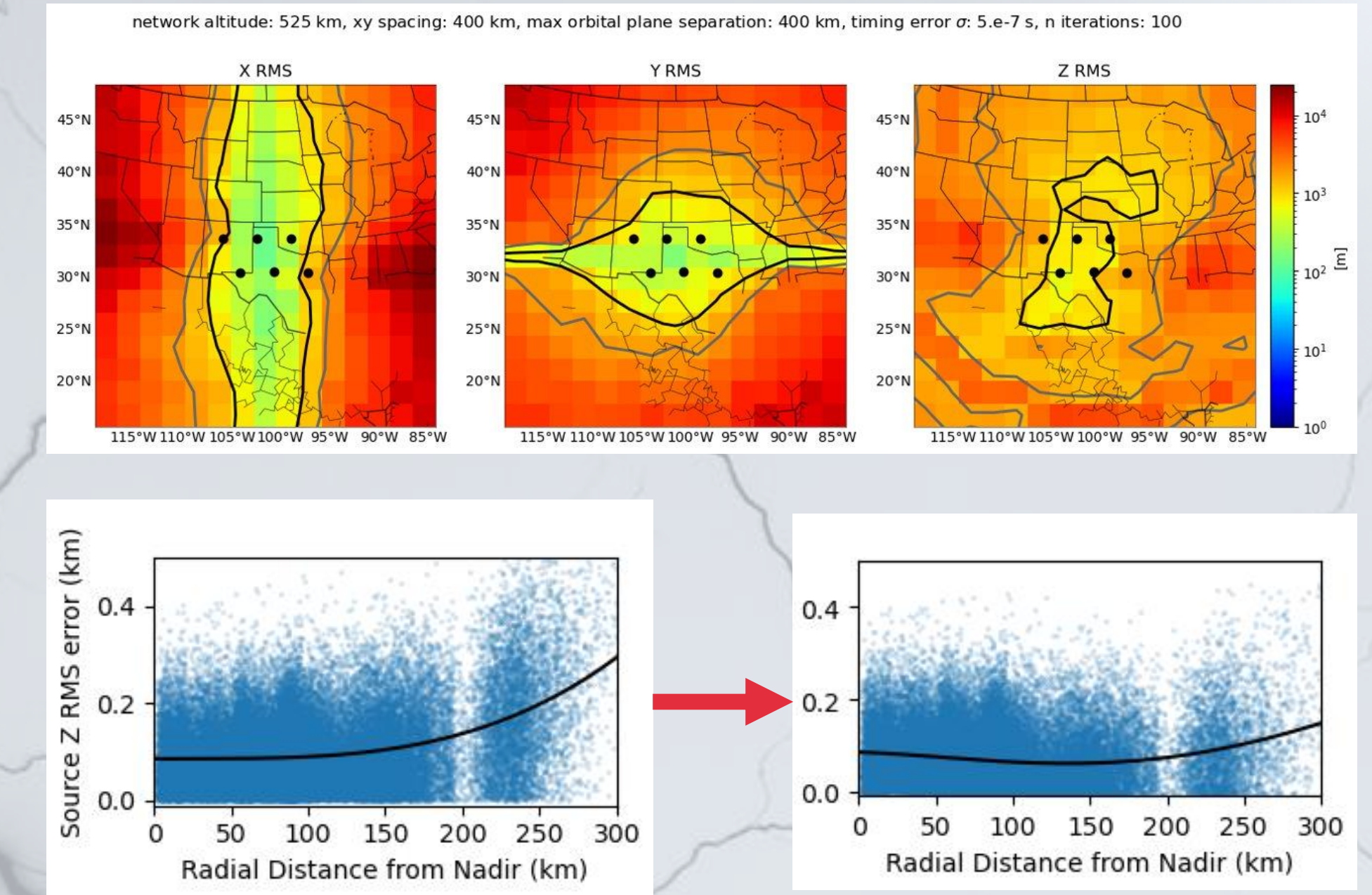
- All 4 spatial coordinates overdetermined from 5+ RF measurements
- Reconstruction depends only on source power and arrival time



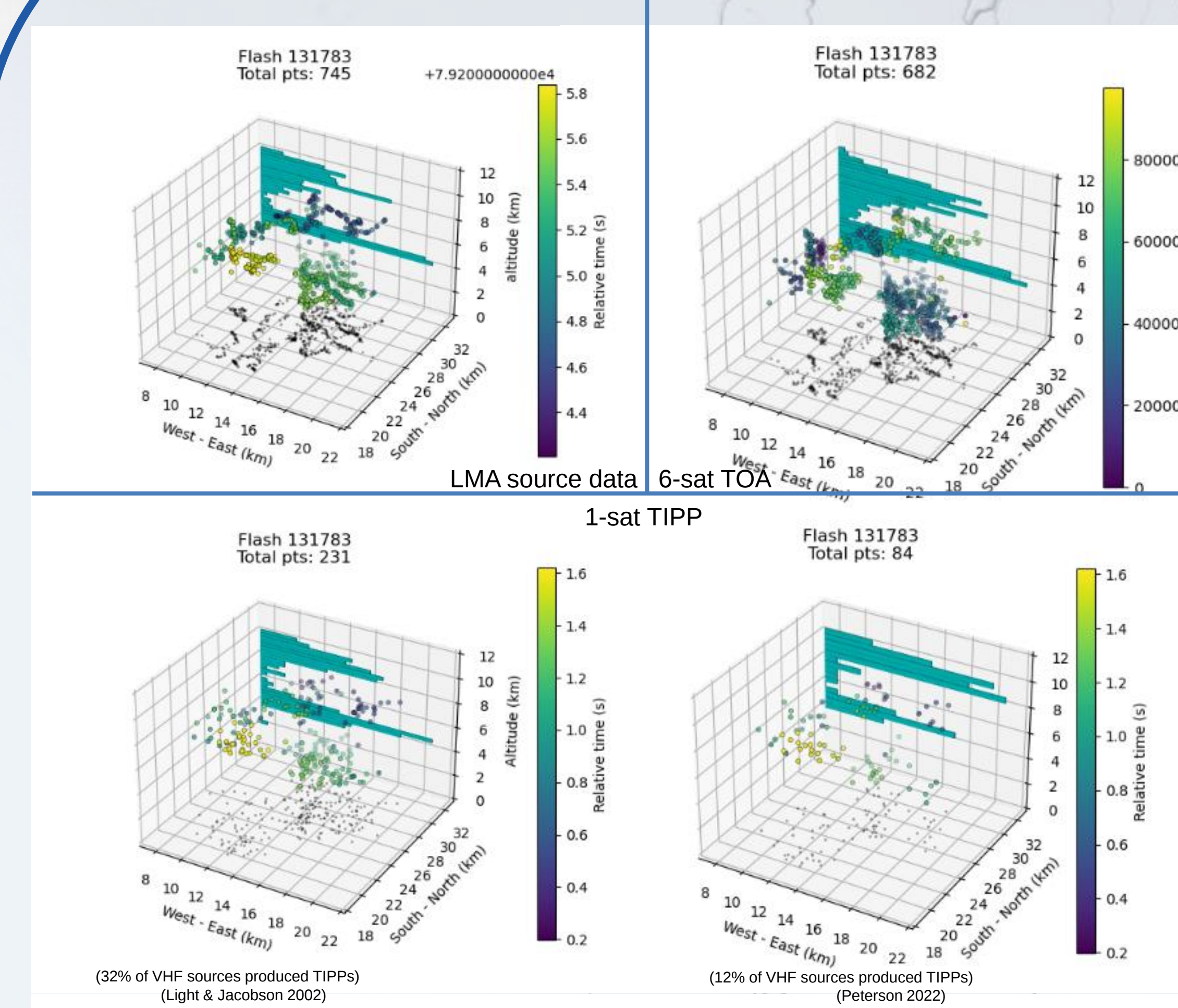
Atmospheric simulations

Simulation work of these methods is based on the LMA simulation package (Chmielewski & Bruning 2016), modified for orbiting detectors.

- Simulates individual VHF sources based on real LMA data recorded at networks in North Alabama, West Texas, and Argentina (Relampago). Sources are analyzed in the predicted overlapping field of view directly below the center of the network out to a 300 km radius.
- Ionospheric dispersion of RF signals are simulated and corrected, with resulting uncertainty in arrival time constrained by GPS clock (conservatively 0.5 μ s). The pure RF TOA method uses these arrival times to determine 3D source locations with RMS error of <2 km vertically and <500 m horizontally
- The TIPP reconstruction method approximates ground reflection point, resulting in the error's strong dependence on horizontal distance. Once corrected, vertical errors are reliably kept under 0.5 km while the horizontal errors remain fixed by the imager's pixel size (conservatively ≤ 2 km)



Results



Pure TOA approach:

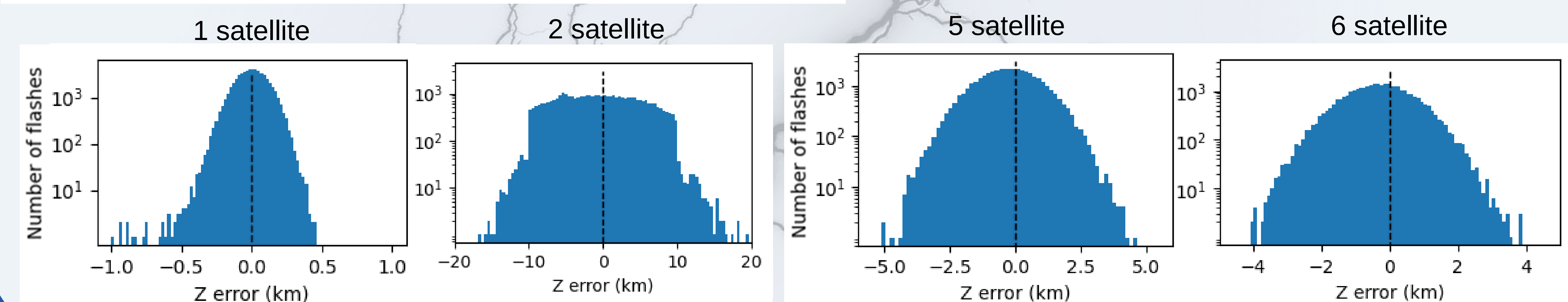
- Average uncertainty (6 satellites):
 - ~0.3 km ave horizontal error (5-sat ~0.5 km)
 - ~1.0 km ave vertical error (5-sat ~1.2 km)
- 80%-90% source reconstruction (noise-dependent) preserves flash geometry better than other methods.

Constrained TOA approach (2 satellites):

- ~1.1 km horizontal error
- ~5.3 km vertical error

TIPP method (1 satellite):

- ~1.2 km ave horizontal error
- ~0.2 km ave vertical error
- Low TIPP detection means up to ~90% fewer sources



3,4 satellite constrained TOA method in progress

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