CubeSpark: 3-D lightning mapping using a constellation of CubeSats

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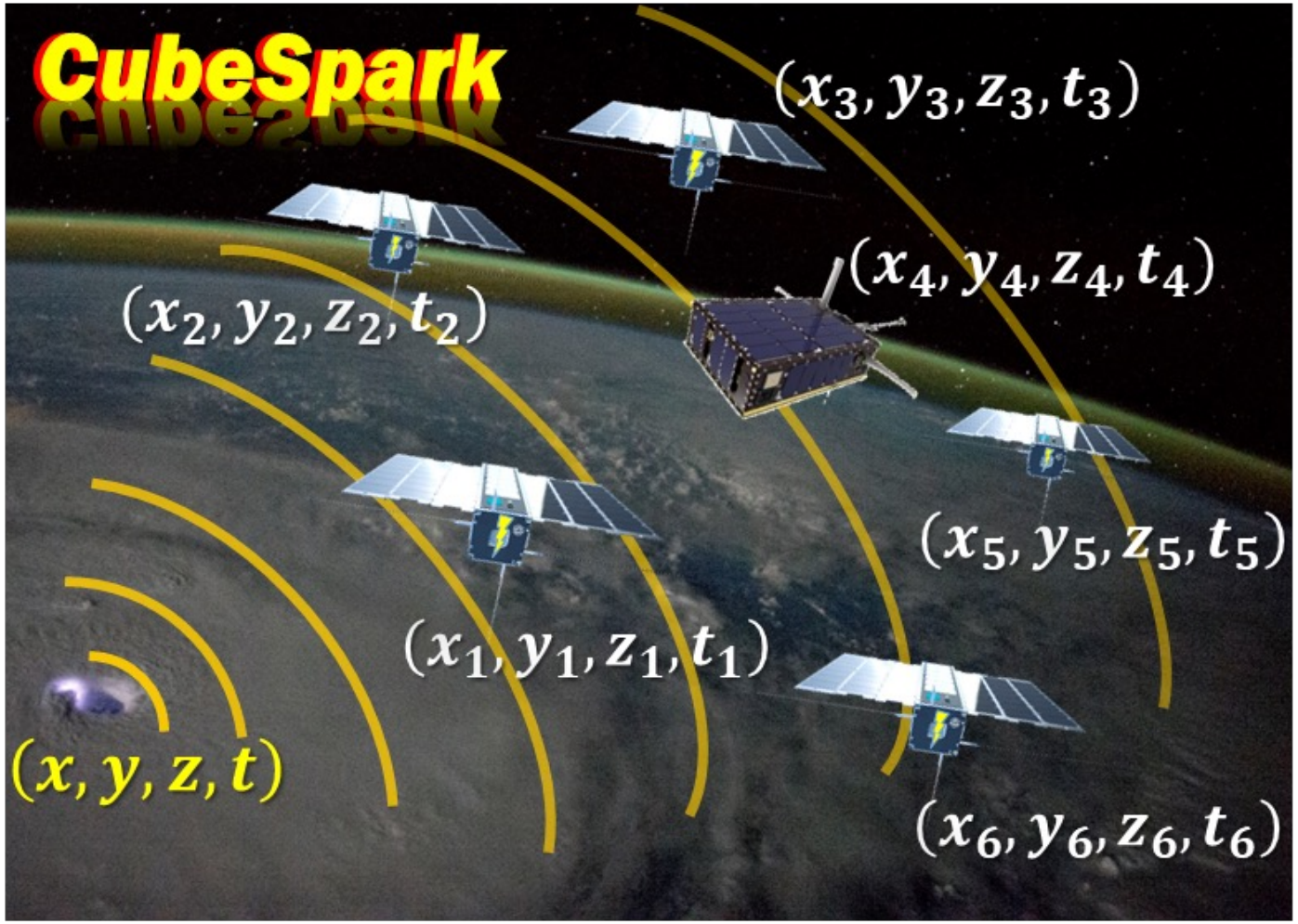
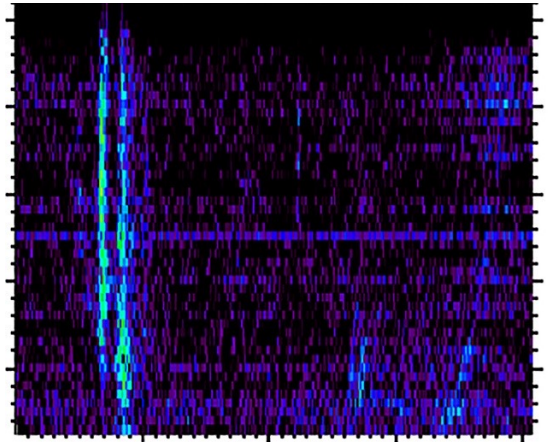
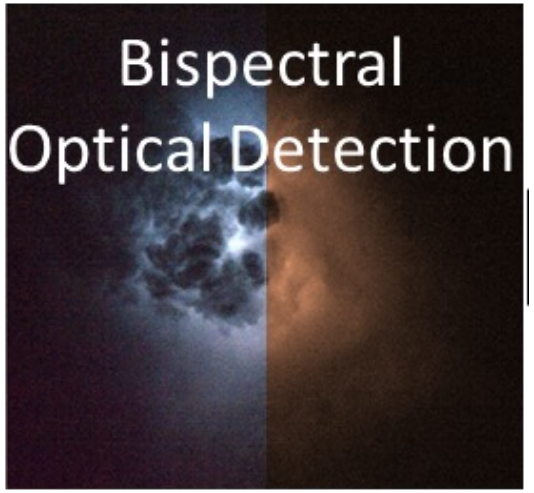
CubeSpark is a concept for a constellation of CubeSats that use combined radio frequency (RF) and optical measurements to detect lightning in 3-D



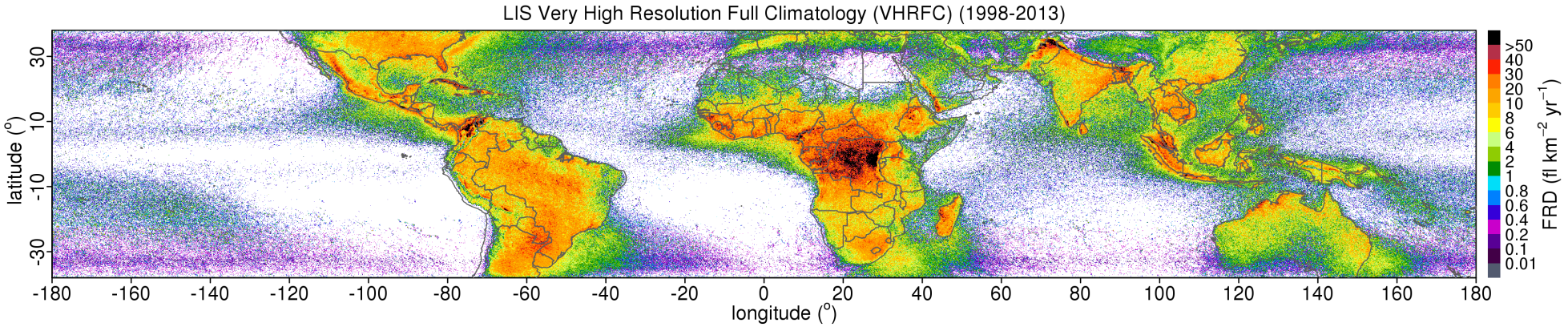


Precise timing of impulsive RF lightning emissions enables 3D geolocation



Optical lightning detection in near-IR and near-UV enhances lightning detection capability

CubeSpark advances the state-of-the-art of space-based lightning detection by adding information on the vertical structure of lightning with RF sensors

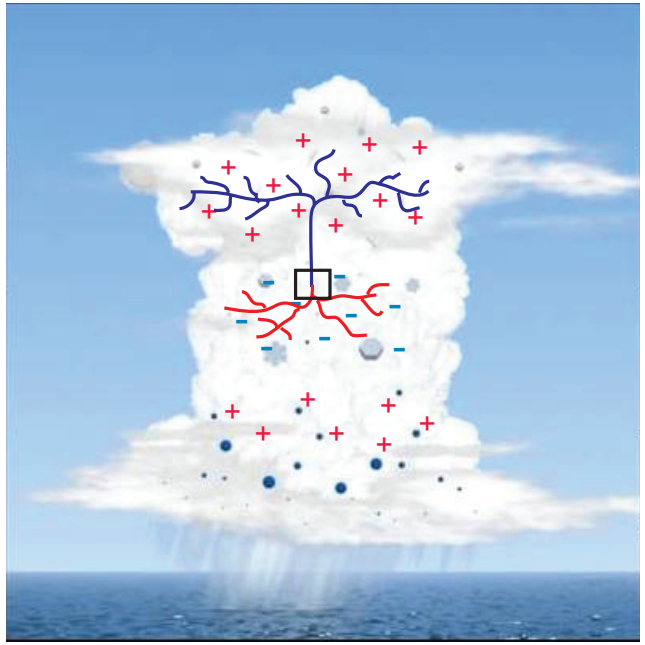


2-D Optical lightning imaging gives information about location and rates of flashes world-wide

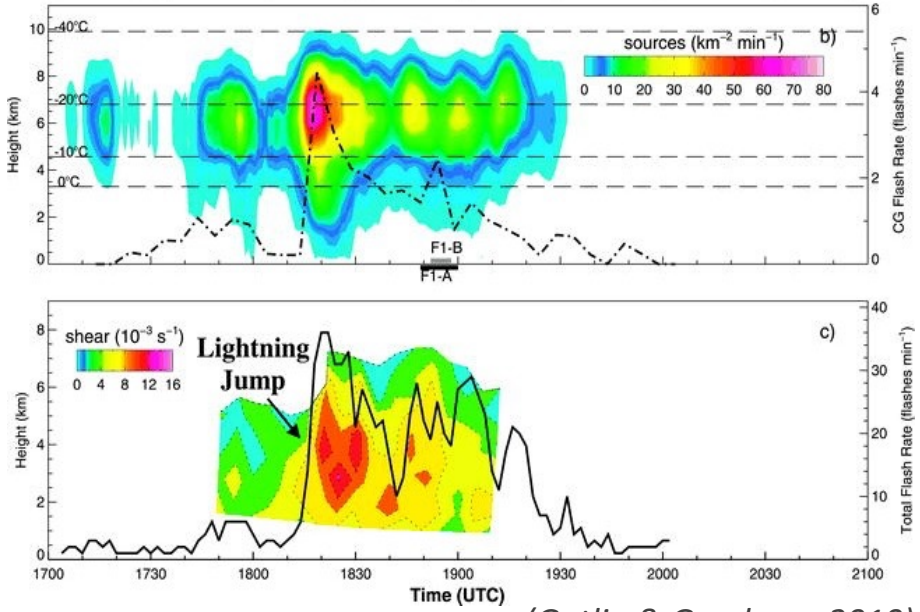
Limitations of space-based optical sensors:

- Limited to 2-D imaging (no altitude)
- Coarse resolution: 4-10 km depending on platform
- Small flashes have low detection efficiency
- Flashes at low altitude have low detection efficiency due to optical depth

Vertical structure of lightning reveals insight into **thunderstorm processes** and can be used a signature of severe weather



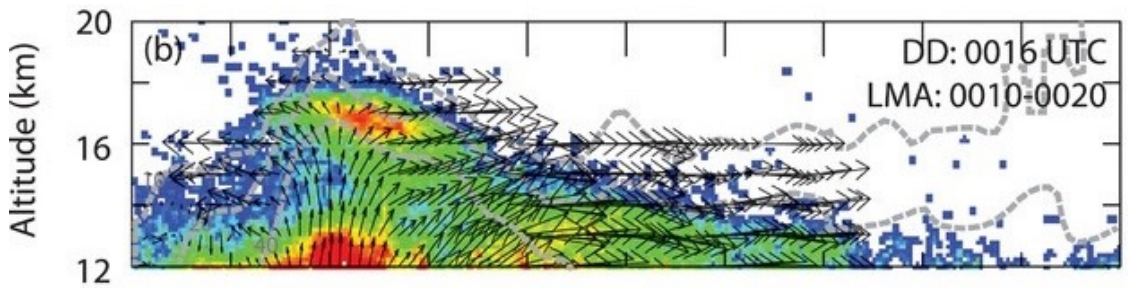
3-D measurements reveal charge structure of storm, which gives locations of charged hydrometeors within thunderstorms



(Gatlin & Goodman 2010)

Storm intensification is associated with a sudden increase in lightning rates and an increase in the altitude of lightning

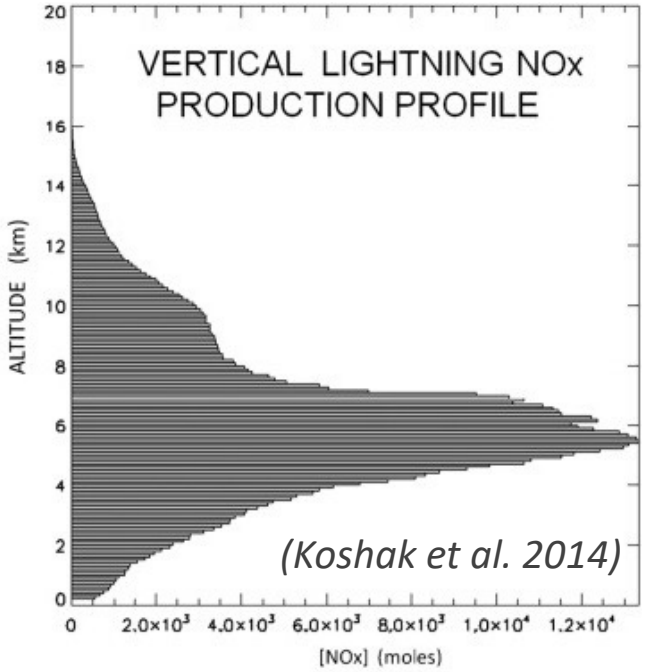
Presence of high-altitude RF sources in overshooting tops of storms is a signature of severe weather



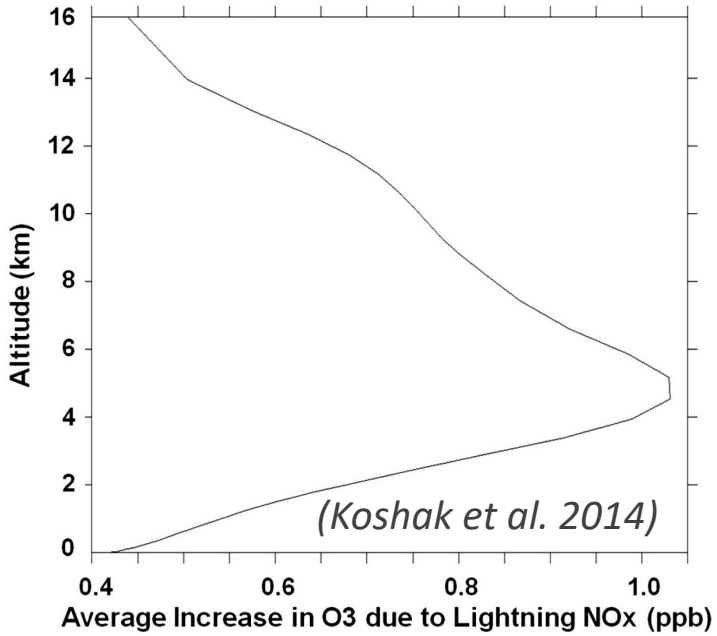
(Calhoun et al. 2013)

Global 3-D lightning measurements important for understanding variability of Lightning NO_X production and impacts to **air quality and climate**

Nitrogen oxides (NO_x) are critical precursors for primary oxidants (O^3, OH) in the troposphere. *Lightning is responsible for ~70% of NO_x in upper troposphere (Schummann & Huntrieser 2007).*

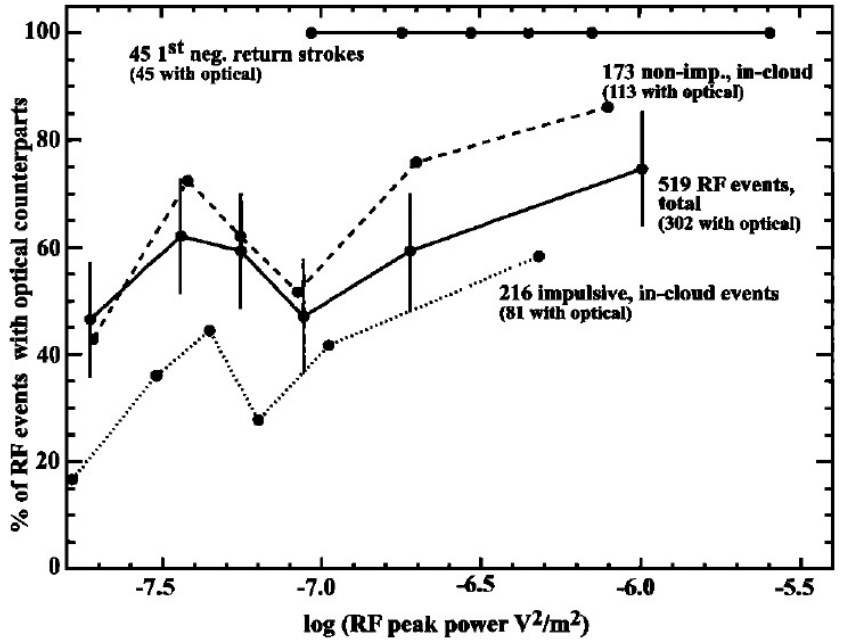


Vertical distribution of LNOx important due to varying transport and depletion mechanisms with height



Lightning NOx impacts ozone concentration.

CubeSpark combines RF and optical to leverage best of both capabilities and boost flash detection efficiency



- Light et al., (2001) studied correspondence between satellite-detected RF and optical emissions
- Out of 647 events:
  - 46% RF and optical
  - 34% RF only
  - 20% optical only

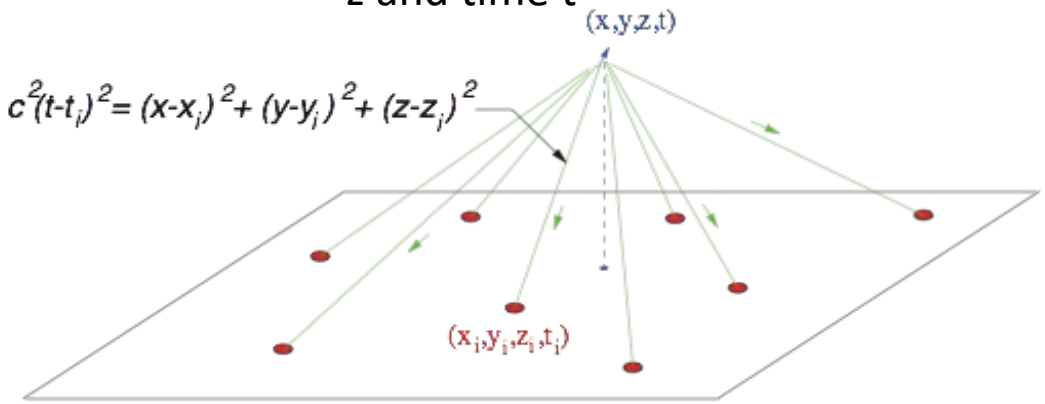
Radio frequency emissions produced by ionization processes during propagation of lightning

Near-infrared emissions produced by heating of lightning channels

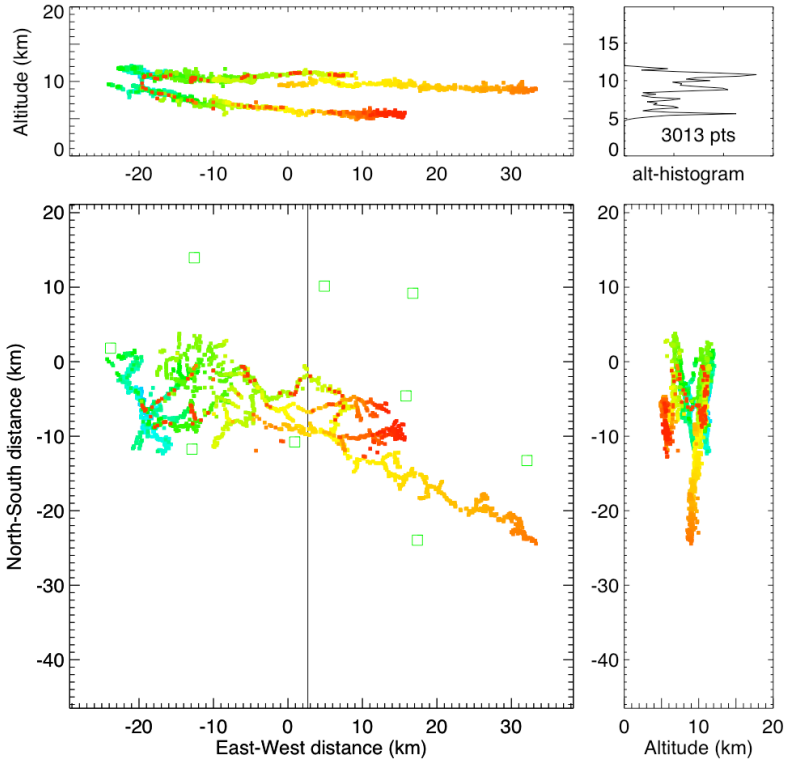
Ultraviolet/blue emissions produced by cold electrical breakdown processes occurring at tips of lightning channels

Lightning produces impulsive radio frequency signatures that enables 3-D geolocation commonly used with ground-based Lightning Mapping Arrays

Lightning source at unknown position x, y, z and time t



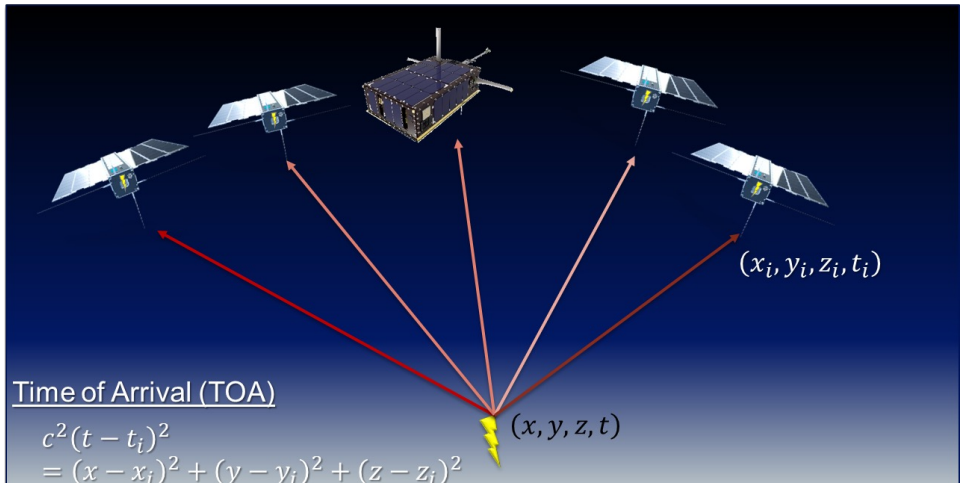
Lightning signal arrives at time ti at stations located at position xi, yi, zi



Source locations of RF sources creates maps of lightning flashes revealing structure of flash

Combining optical and RF measurements from space leads to two approaches for 3-D lightning detection

Multi-satellite, pure RF Time-of-arrival (TOA)

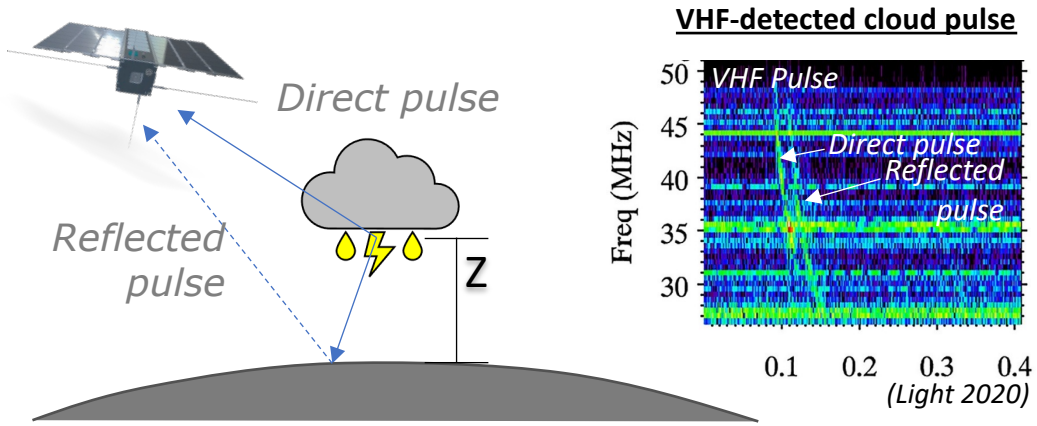


Same methodology as ground-based approach

Retains 2-D flash geometry

Better horizontal accuracy

Single-satellite, Optical (2-D) + RF gives 3-D



Time delay between direct and reflected RF gives height above ground if lat and lon are known

Optical provides latitude and longitude

Better vertical accuracy

Initial simulations demonstrate feasibility of multi-satellite RF TOA approach

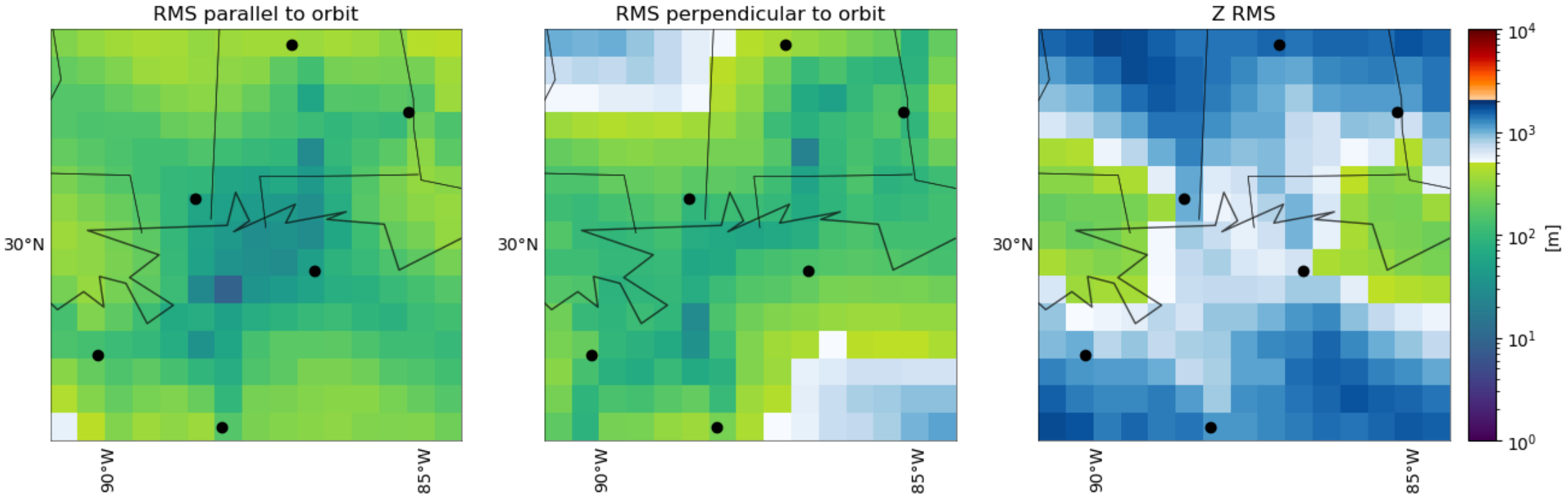
→ Constellation of 6 satellites distributed in two planes in low Earth orbit, ~530 km altitude

→ Required vertical location uncertainty of 2 km; Desired is 1 km

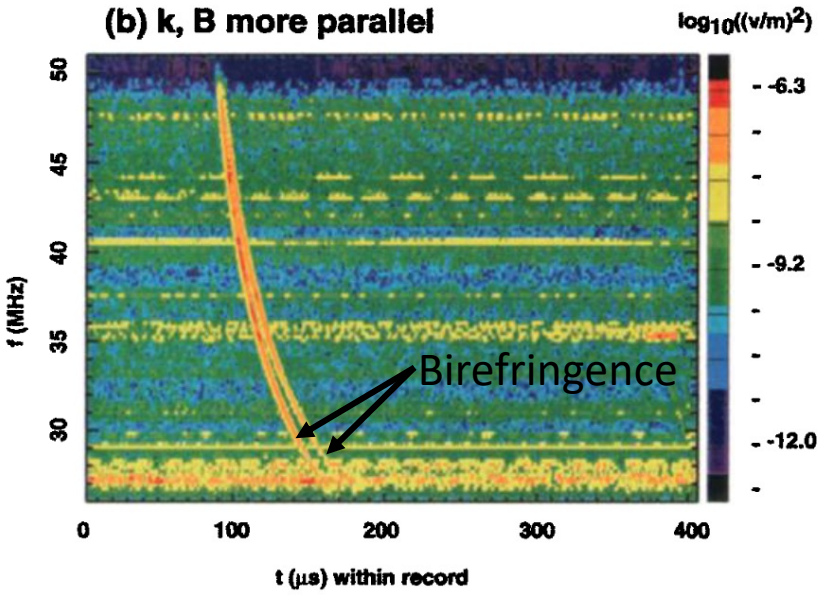
Geolocation uncertainty for moderate TEC (30 TECU), instrumental timing uncertainty of 100 ns

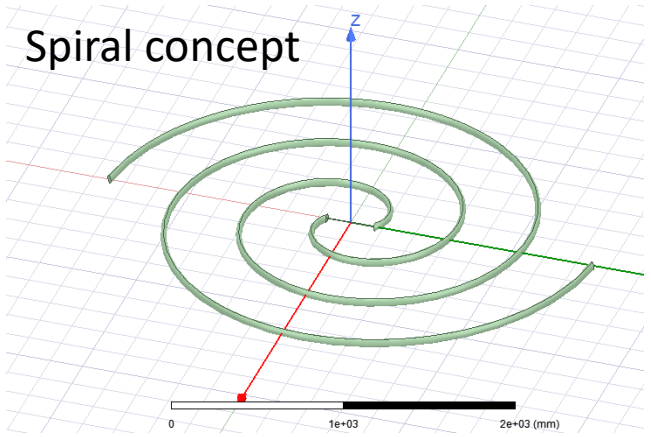
Average Horizontal Uncertainty: 334 m

Average Vertical Uncertainty: 940 m



RF instrument development focused on miniaturization, robust antenna performance and improved signal detection strategies



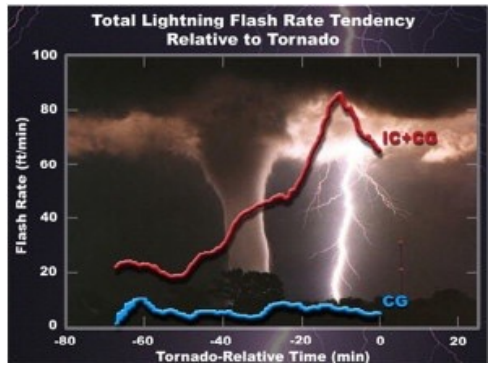


Circular polarization from spiral design suppresses one of two birefringent wave modes caused by coupling of ionospheric plasma and geomagnetic field

- CubeSpark is a concept in development to make 3-D measurements of lightning from space

- Enables numerous science applications from thunderstorm processes to climate

- Orbital simulations demonstrate feasibility of approach using constellation of 6 satellites in two planes



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