Where’s my GPS? Is it really blocked by trees?

Predicting UAV GPS Impairment by Buildings and Foliage

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We would like to thank the many people who made this work possible, including:
- Sloan Glover (Raycasting engine)
- Collaborators at NASA and Mitre, especially Evan Dill and Arthur Scholz
- NASA Langley Research Center GIS Group

Outline

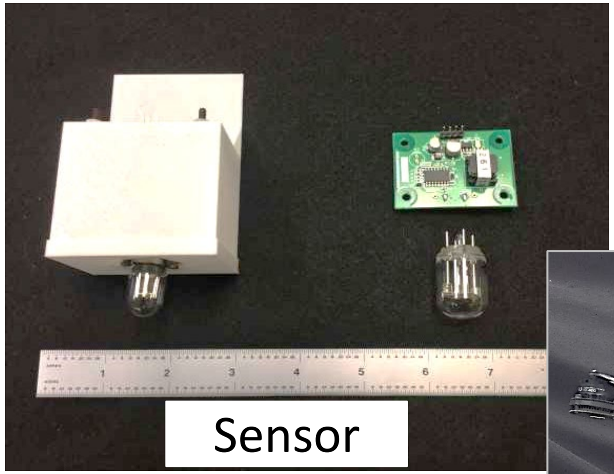
- Project Background – what motivated this work
- Brief overview of the physics and operational risk of GPS loss
- Examples of forecasting GPS quality at 3 sites
    1. Buildings only
    2. Buildings + trees
    3. Trees only <---- special focus today
- The Attenuation vs. Foliage Depth Curve
- What this means for flying in canyons, urban and arboreal
- Two research products: survey method and quality calculator
- Q&A

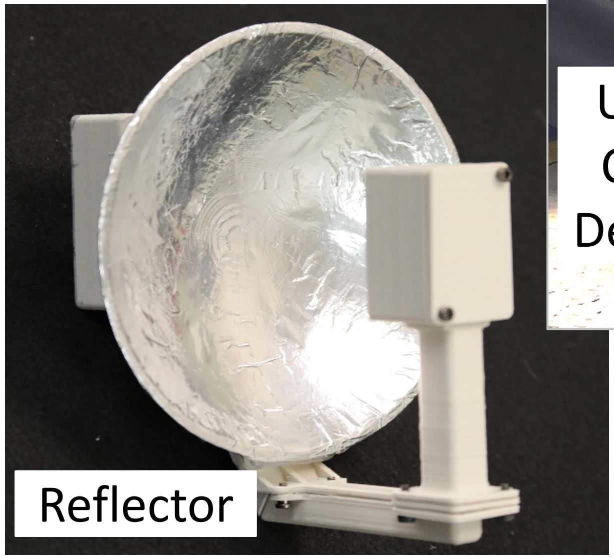
Conclusions

1. Flight ranges in forests can be surveyed to calibrate the severity of GPS attenuation
2. It is possible to forecast navigation fidelity in urban and arboreal canyons

Sometimes GPS is great…

Affordable Flame Sensor to Detect UV Corona, Verified against UV Camera
2016 Flight Campaign: Georgia Flights





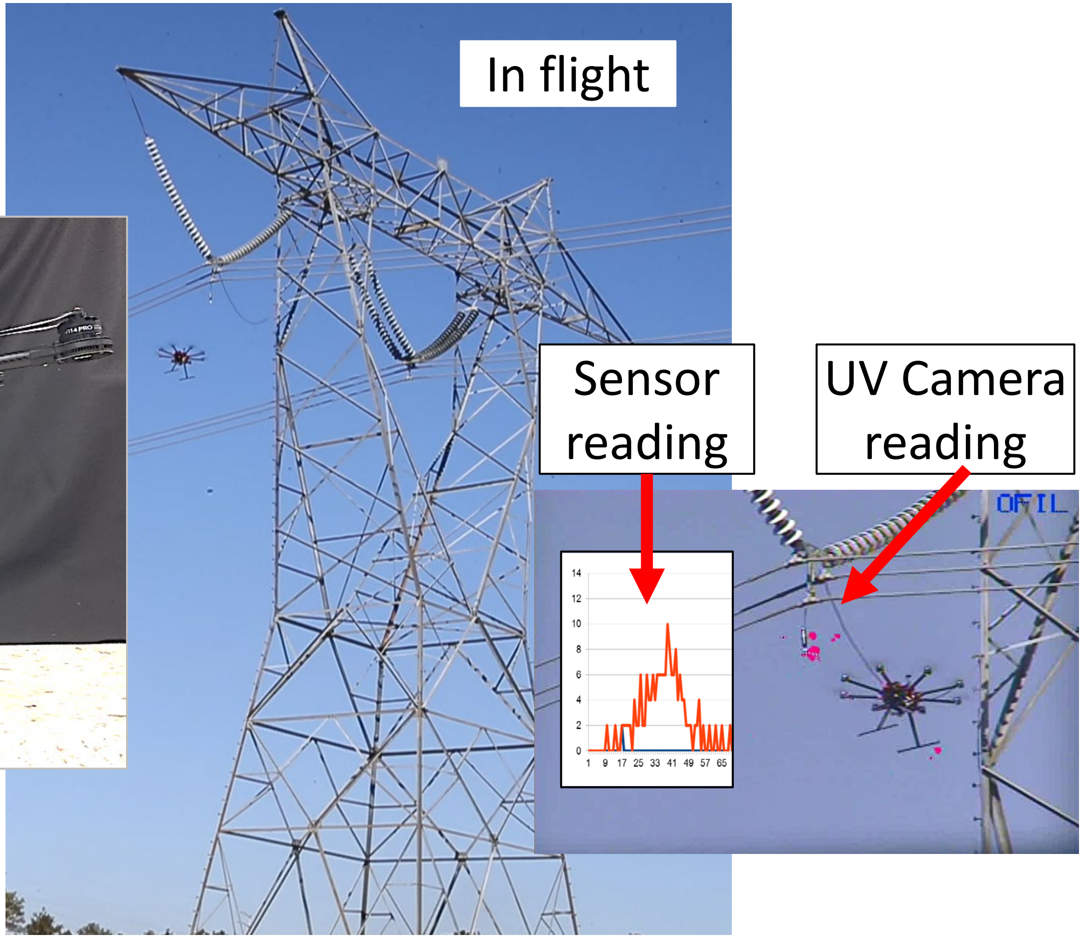
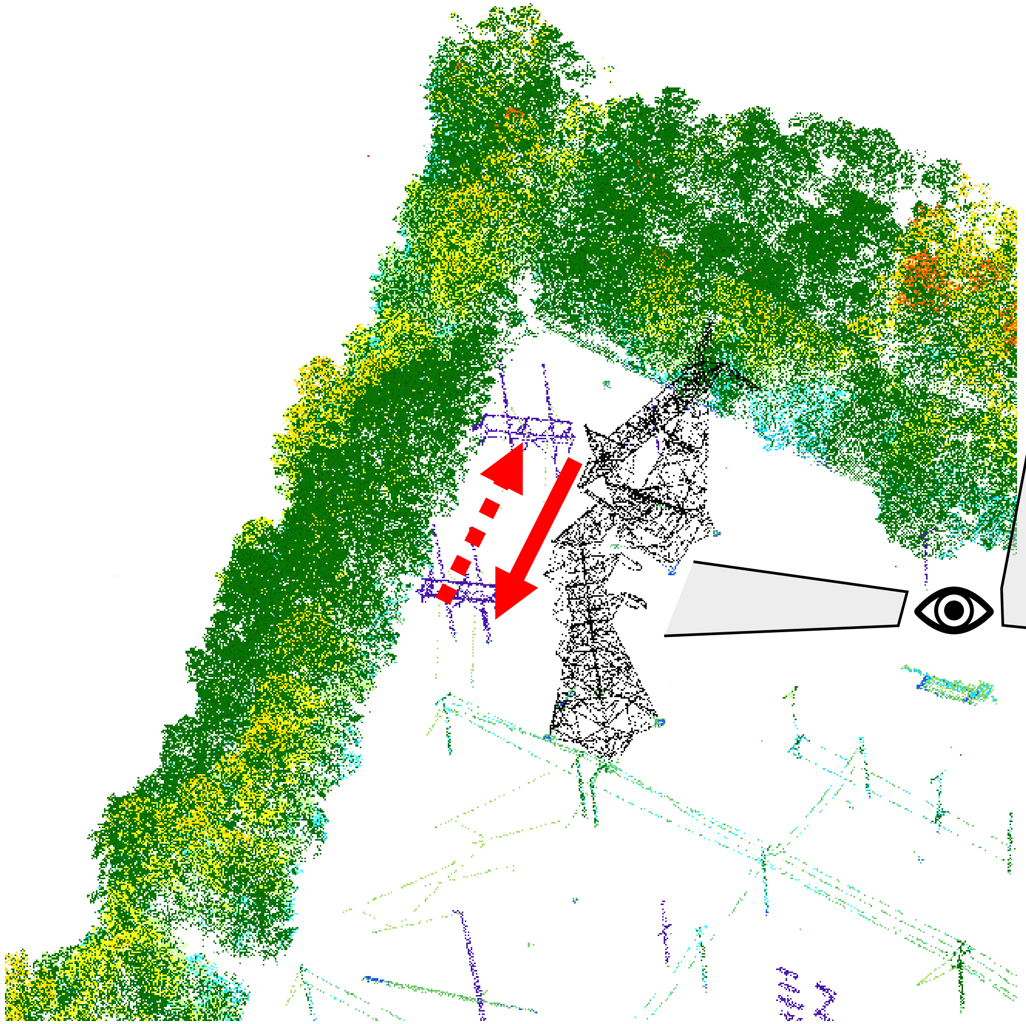


Image credit: NASA

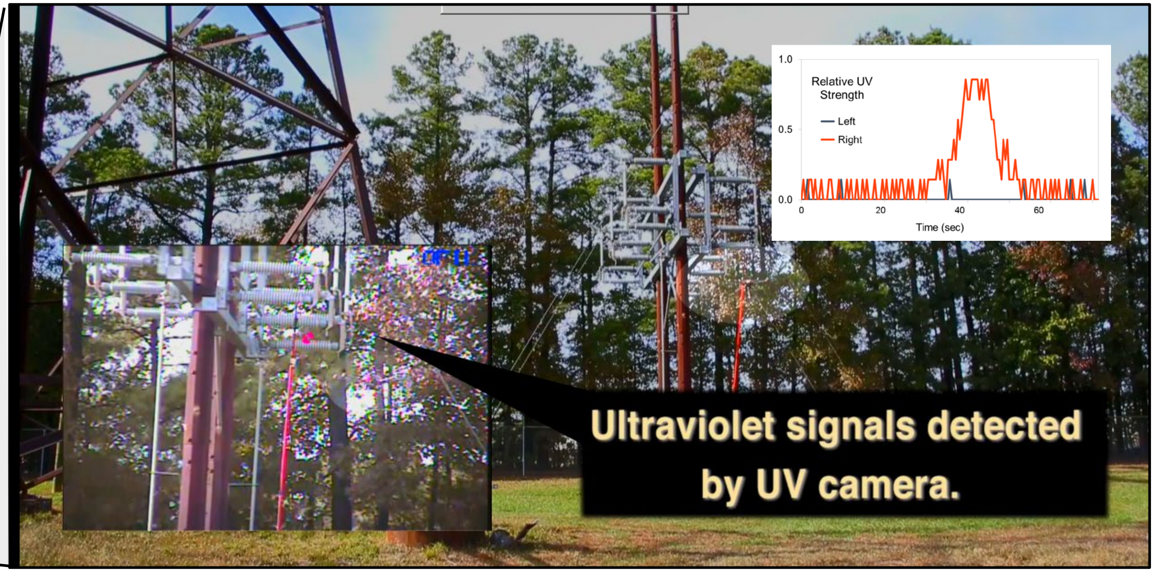
Moore, Andrew J., Matthew Schubert, and Nicholas Rymer. "Technologies and operations for high voltage corona detection with UAVs." 2018 IEEE Power & Energy Society General Meeting (PESGM). IEEE, 2018.

… and sometimes GPS is intermittent

2016 Flight Campaign: Virginia Flights



Dominion's Chester Virginia flight range. ©*Lidar data: Dominion Virginia Power*



One flight path worked, the other didn't.

- Was GPS blocked by the trees?
- Reflected by the towers?

We don't know.

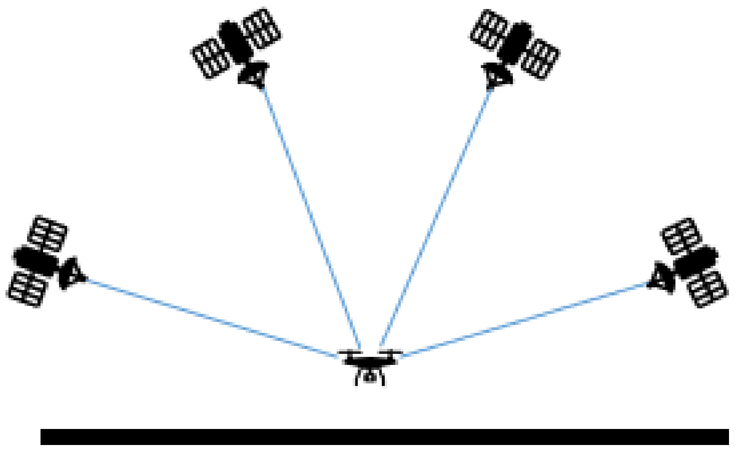
Moore, A.J., Schubert, M. and Rymer, N., 2017. Autonomous Inspection of Electrical Transmission Structures with Airborne UV Sensors-NASA Report on Dominion Virginia Power Flights of November 2016.

Why GPS can be poor at low altitude

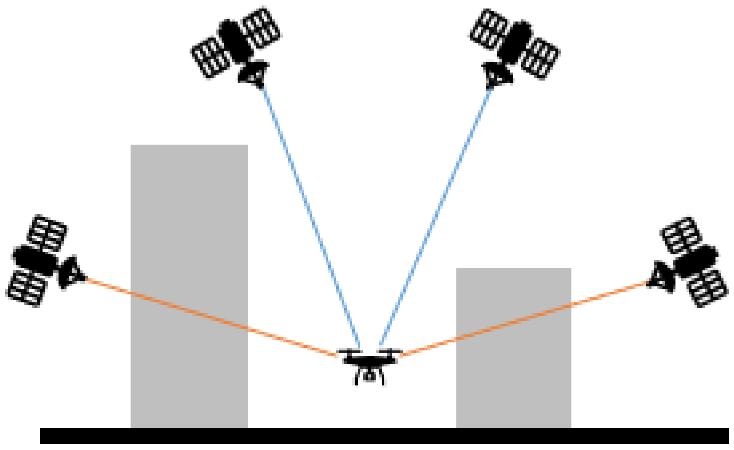
Both the number of satellites and their geometry determine the position fidelity, usually specified as a dilution of precision (DOP) in meters.

- You need good horizontal spread for horizontal accuracy (low HDOP)
- You need good vertical spread for vertical accuracy (low VDOP)
- Signal reflections off of buildings (called ‘multipath’) can cause false position reading

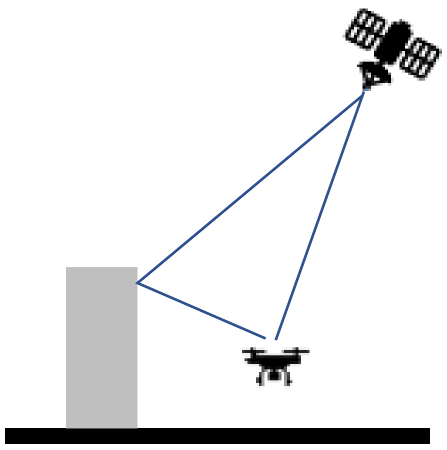
Good horizontal and vertical fidelity



Blockage by buildings -> Poor vertical fidelity



Building reflection -> Poor H+V fidelity



Graphics: NASA

GPS loss – computing the physics is a 2020's development

UAS navigation is often hindered by degraded GPS position quality

- 4+ satellite lines of sight are needed for good fidelity
- Blockage and reflection by buildings
- Blockage and attenuation by foliage

Three research groups (one at Google[1] and two at NASA[2,3]) are computing GPS quality by tracing from the UAV to orbiting satellites.

- Building blockage is addressed by all three
- Foliage blockage is addressed by one

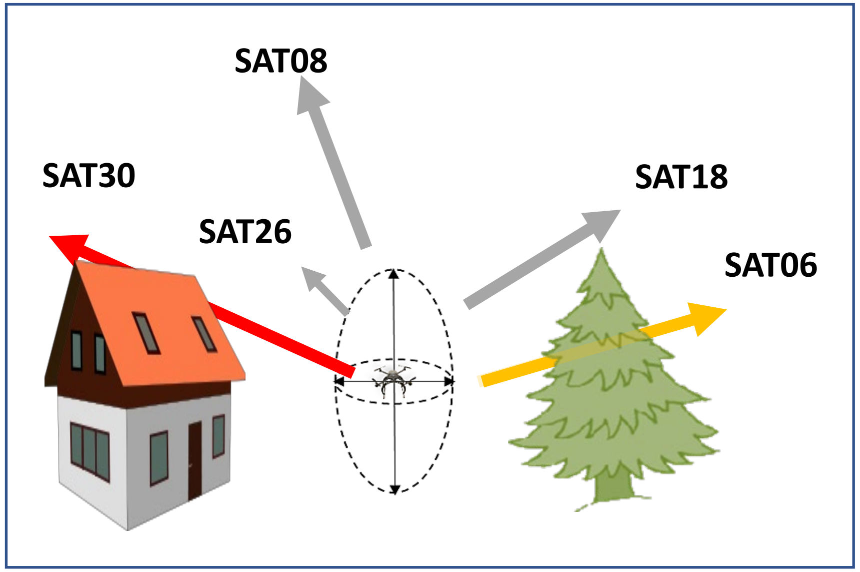


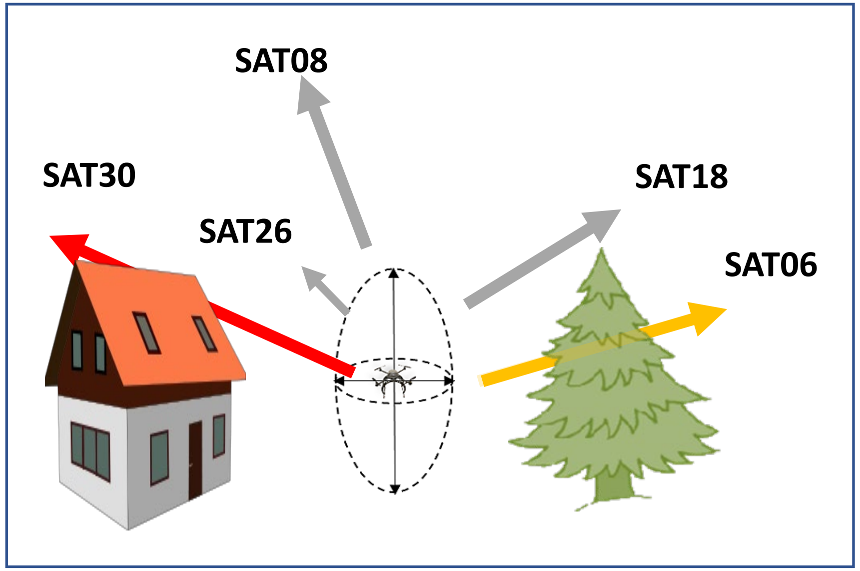
Figure 1. GPS signal blockage a UAV might experience.
Graphics: NASA, NOAA, USDA

1. F. van Diggelen, "End Game for Urban GNSS: Google's Use of 3D Building Models," Inside GNSS, March/April 2021, Vol. 16(2), pp. 42-49, 2021.
2. E. Dill, Evan et al. "A Predictive GNSS Performance Monitor for Autonomous Air Vehicles in Urban Environments." Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021). 2021
3. A. Moore , M. Schubert, N. Rymer , D. Villalobos , J.S. Glover , D. Ozturk and E. Dill, "Volume Raycasting of GNSS Signals through Ground Structure Lidar for UAV Navigational Guidance and Safety Estimation." AIAA Scitech 2022 Forum. 2022

Three examples of forecasting GPS quality

Results from the two NASA efforts

1. Buildings only
2. Buildings + trees
3. Trees only



Graphics: NASA, NOAA, USDA

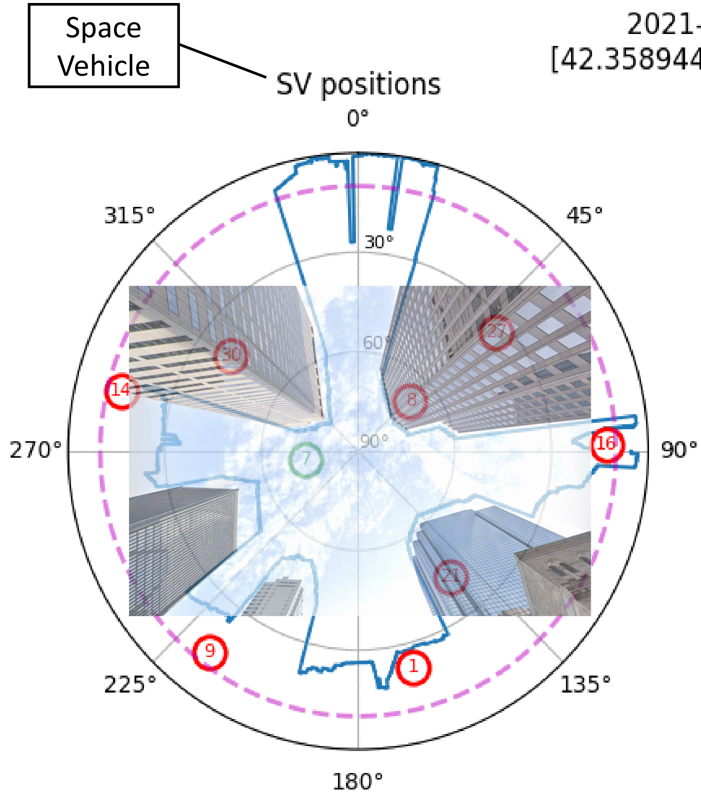
Notes: Example 1 uses U.S. GPS satellites only
Examples 2 and 3 use GPS + GLONASS satellites
Reflections (multipath) are not computed – for better or worse

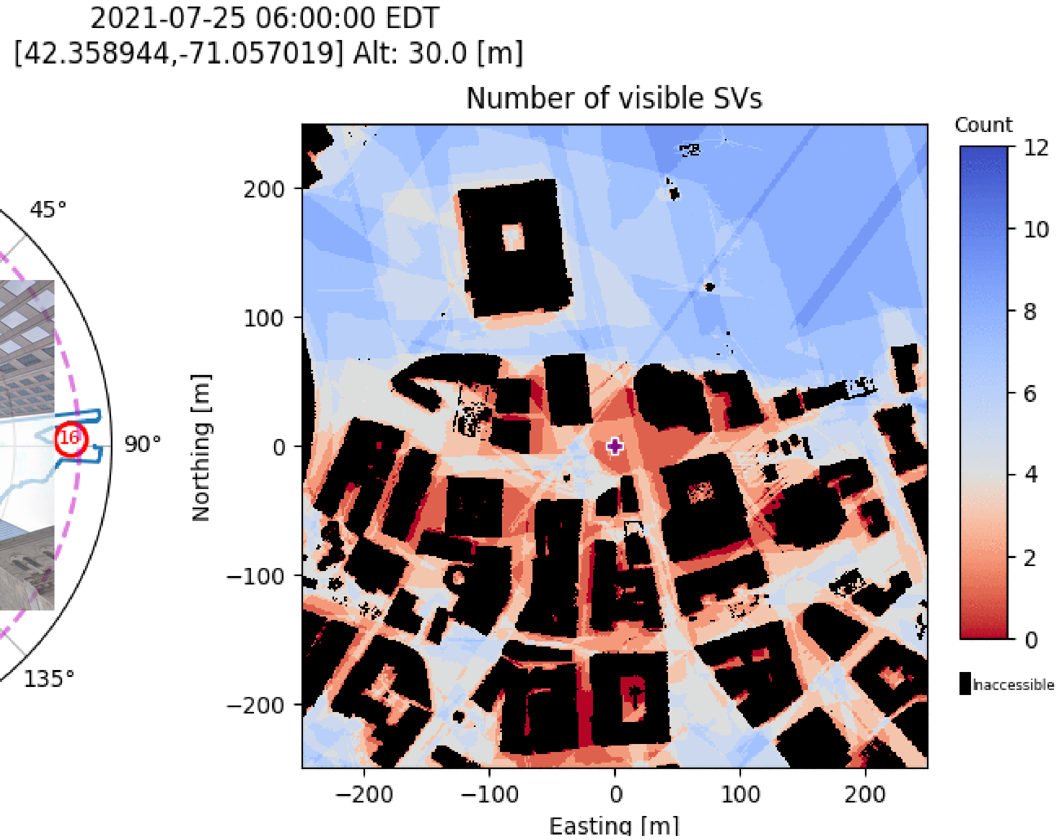
Example 1. Buildings only

Downtown Boston

To orient you to what you will see next…

Computed GPS quality forecast over a 6 hour period





Skyplot: Blue outlines are the tops of buildings

Fidelity map

3D top down view: Yellow box is at 30m altitude

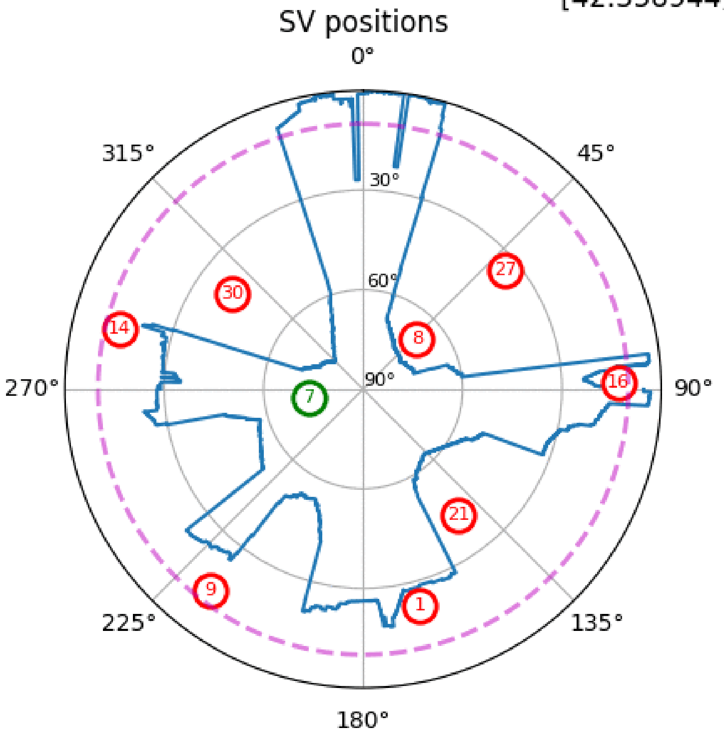
Map data: © 2021 Google Earth (Landsat, Copernicus); Image and graphics credit: NASA

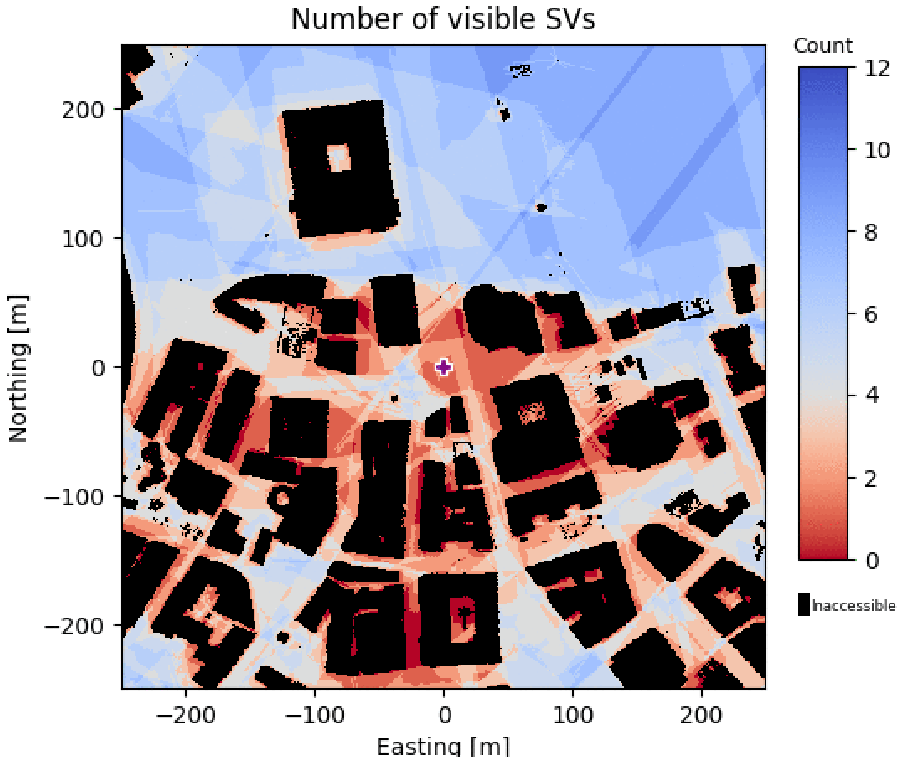
Example 1. Buildings only

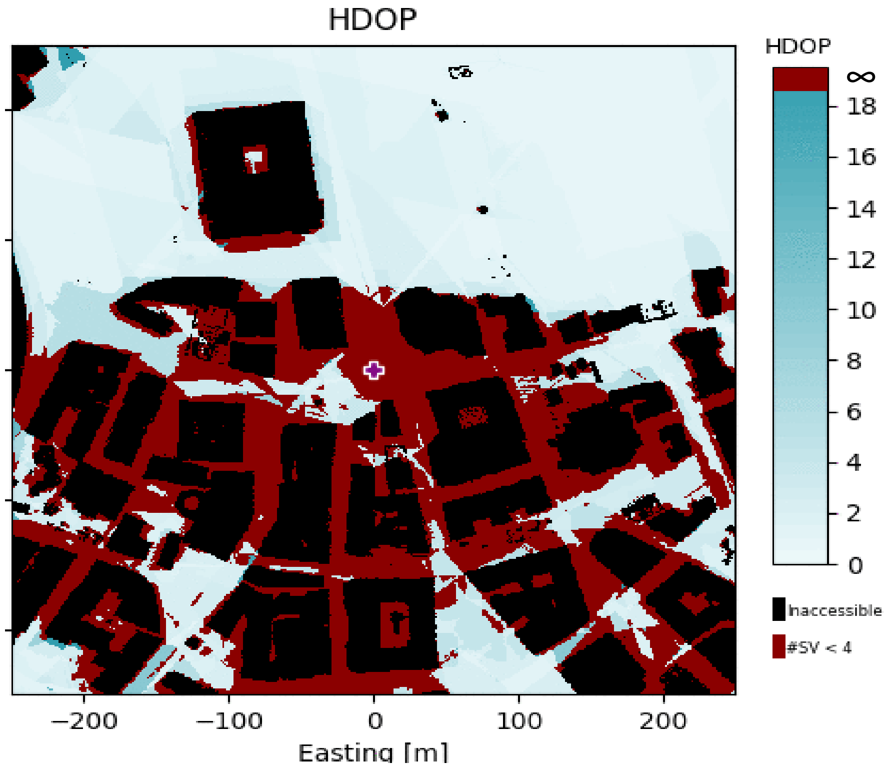
Downtown Boston

→ Buildings block 100%

2021-07-25 06:00:00 EDT
[42.358944,-71.057019] Alt: 30.0 [m]



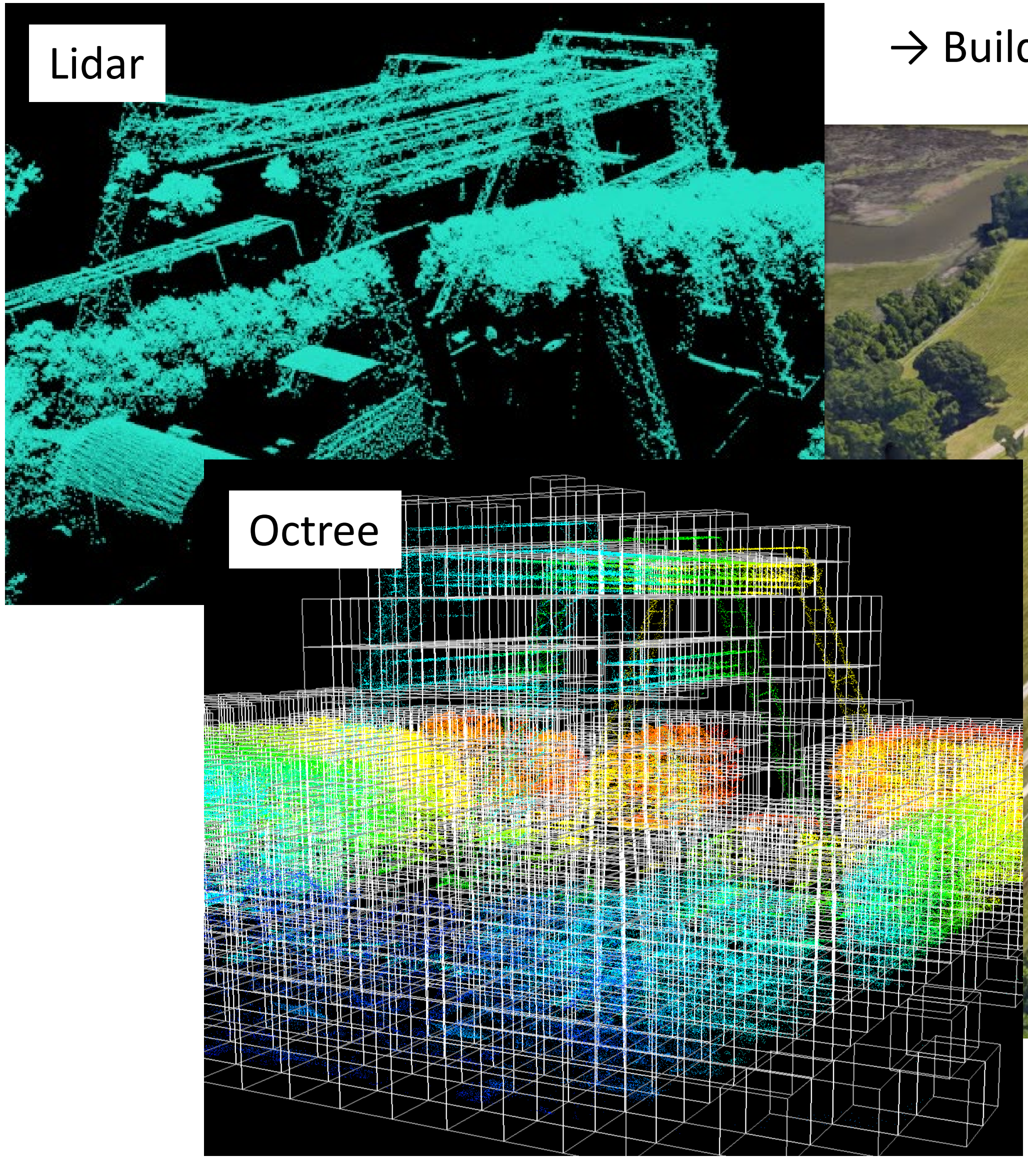




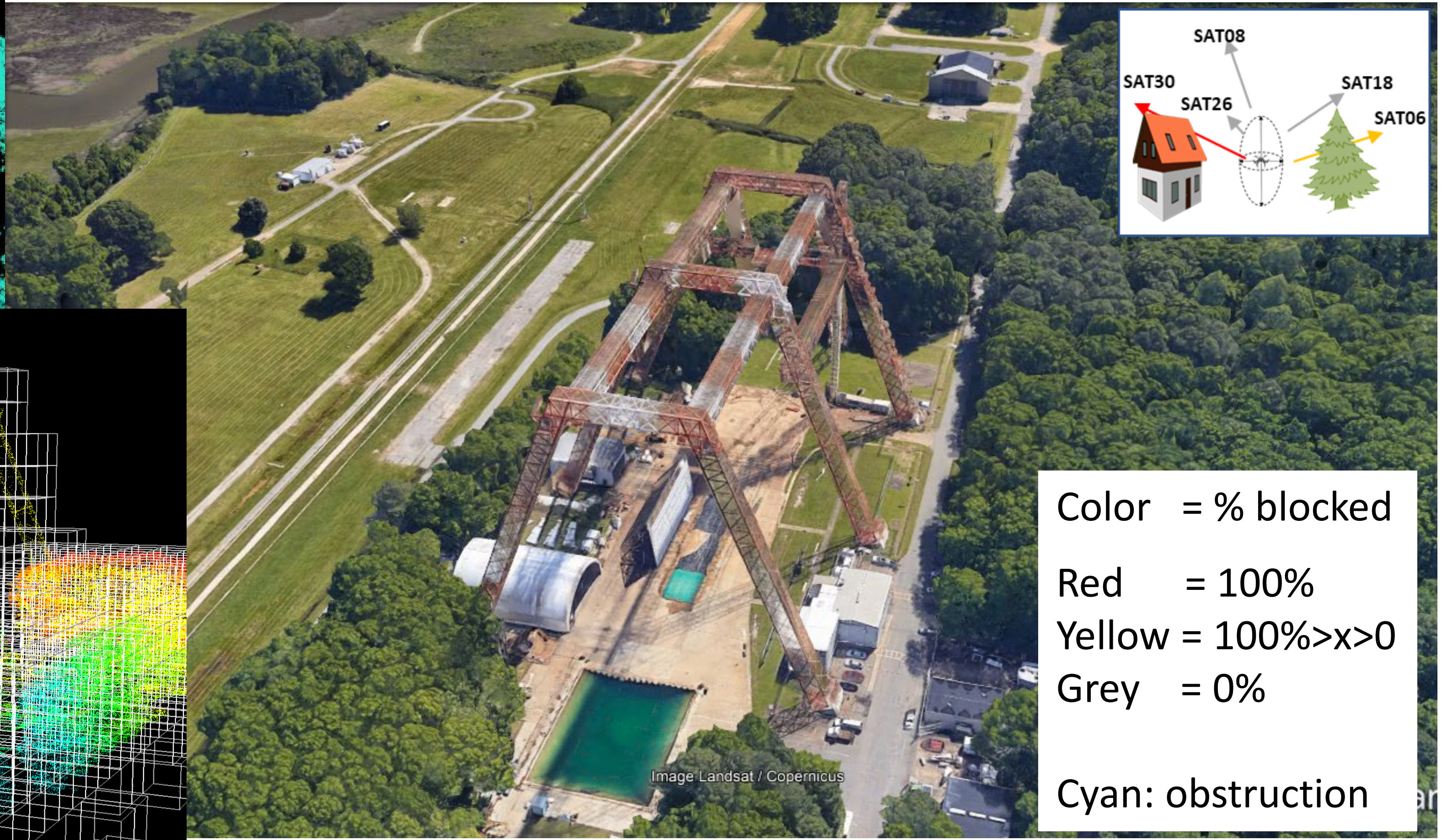
Map data: © 2021 Google Earth (Landsat, Copernicus); Image and graphics credit: NASA

Example 2. Buildings + trees

NASA Langley Lunar Lander Research Facility, March 2018 flight



→ Buildings block 100%, foliage attenuates at 20% per meter.

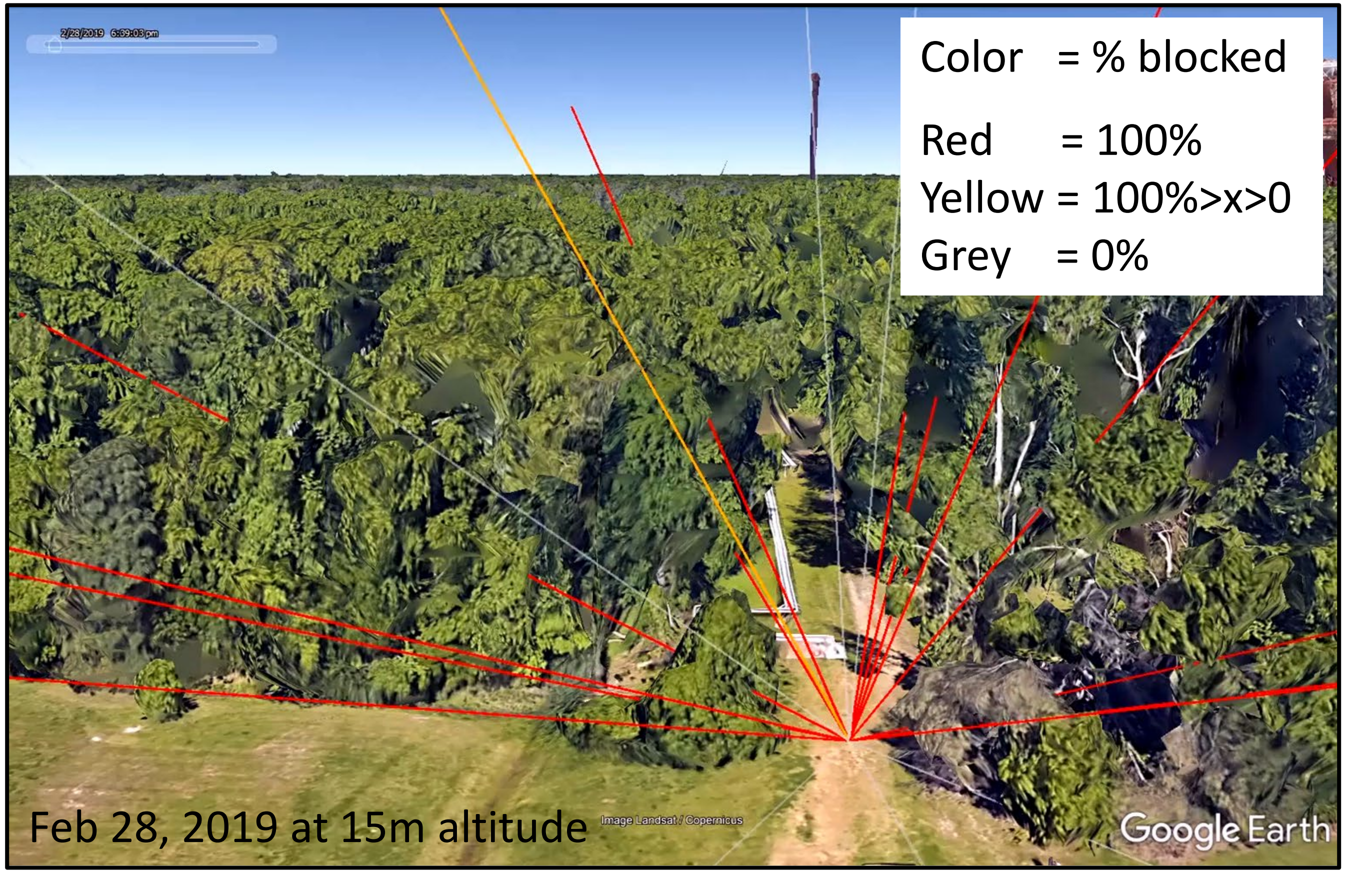


Map data: © 2021 Google Earth (Landsat, Copernicus); Image and graphics credit: NASA

Example 3. Mostly trees

Arboreal canyon with steam pipeline

→ Foliage attenuates at 20% per meter.

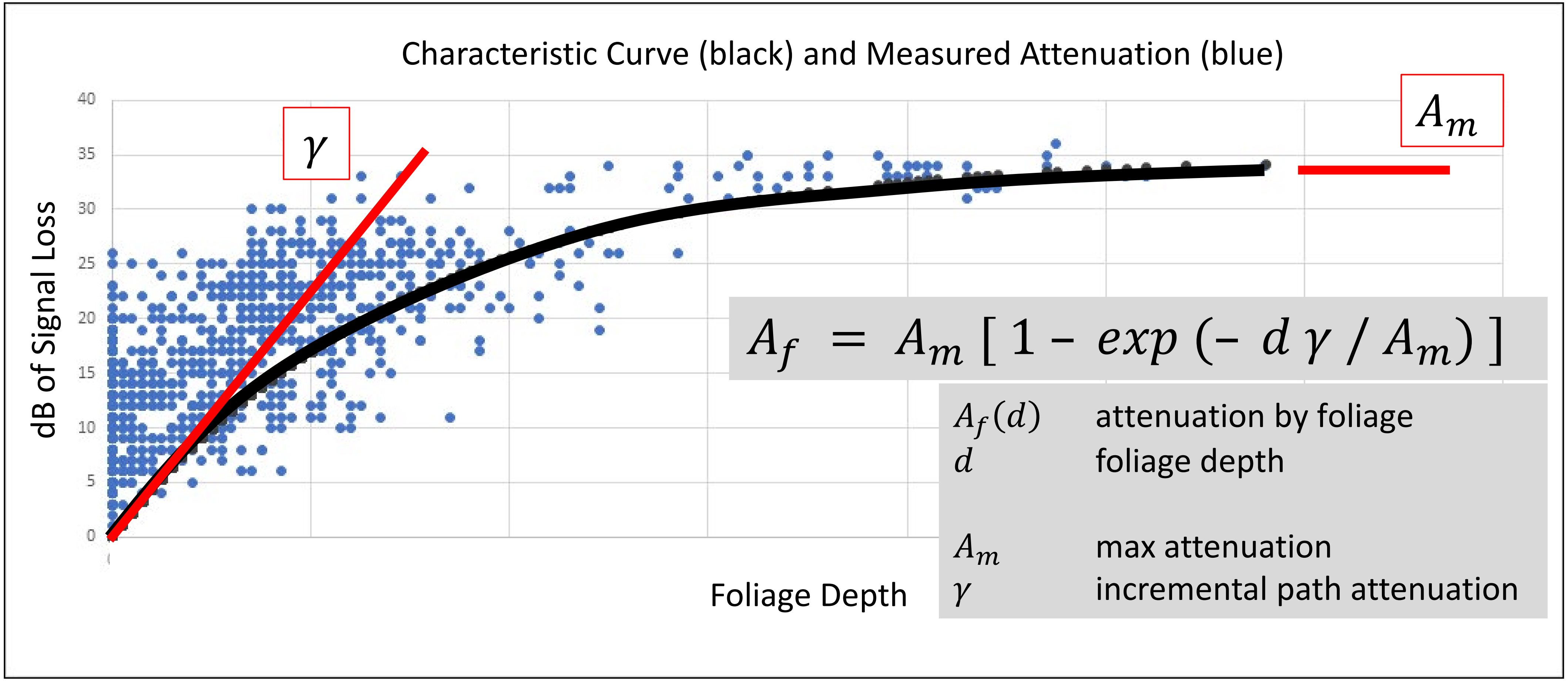


Map data: © 2021 Google Earth (Landsat, Copernicus)

What is the real % blockage per meter of foliage?

Collected 55 recordings at various altitudes on 14 days over ~ 2 years (November 2018 to February 2021)

Consistent result: GPS signals are attenuated by vegetation according to a saturating exponential



- X axis: Meters of foliage between UAV and satellite
- Y axis: Drop in signal strength from ‘clear sky’ sample

A characteristic curve for GPS attenuation by foliage

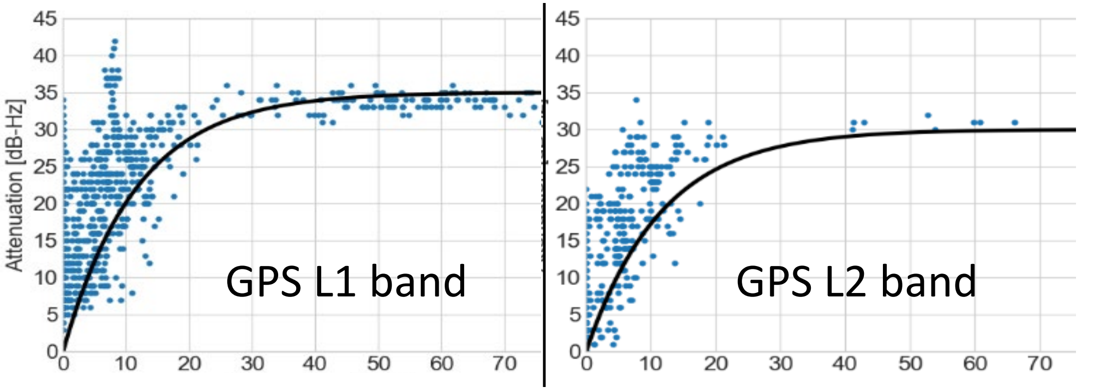
Experimental results

- Left: GPS L1 results. A representative single measurement (top) and all L1 results (bottom).
- Right: GPS L2 results. A representative single measurement (top) and L2 results (bottom).

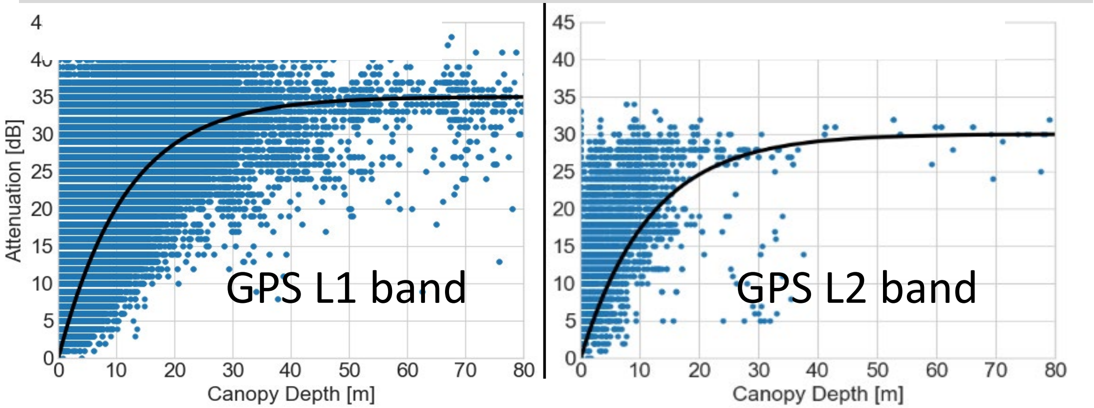
Consistent finding: results follow a curve[2] similar to continuous-wave radio attenuation – but with 10X steeper γ (dB/m)

- $A_f = A_m\left[1 - \exp\left(-\frac{d \cdot \gamma}{A_m}\right)\right]$
- $A_{m,\text{GPS}} \sim A_{m,\text{continuous-wave}}$
- $\gamma_{\text{GPS}} \sim 10 * \gamma_{\text{continuous-wave}}$

Data from a single recording[1]



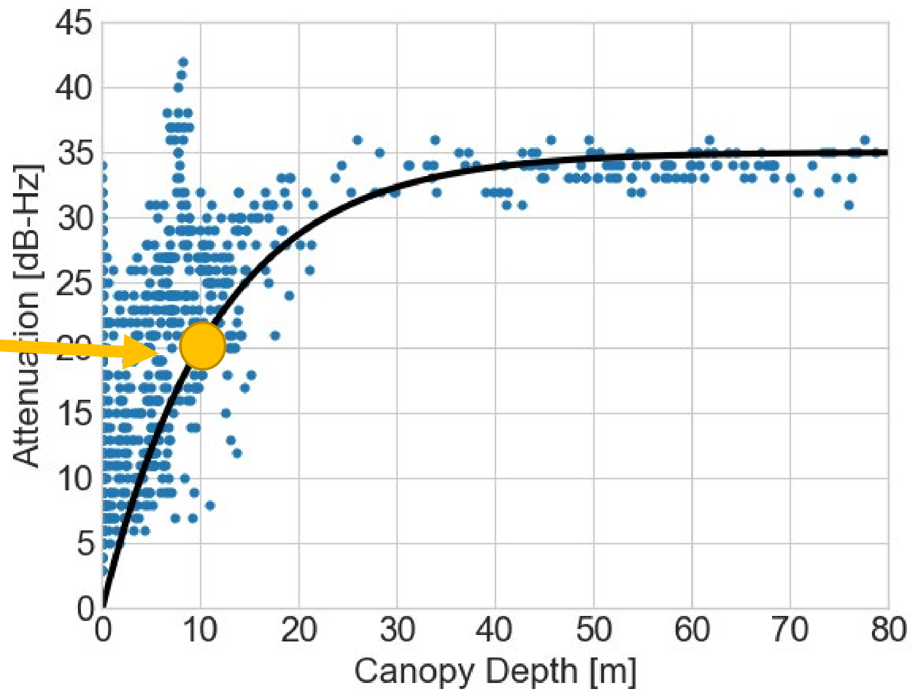
All data acquired across 2 years

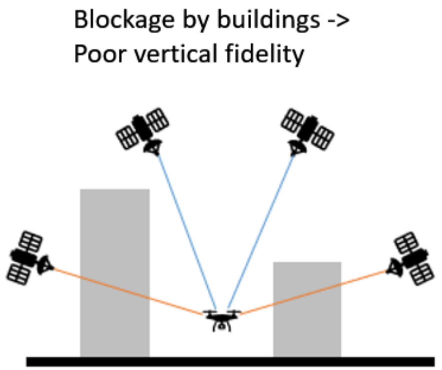


1) February 10, 2021
2) International Telecommunication Union "Attenuation in Vegetation" ITU-R Recommendation P833-9, Geneva, September 2016

Implications for flying in arboreal canyons

- *For this mixed hardwood canyon*,* after about 30m of foliage blocking, the signal loss is near the maximum.
  - 60% of signal lost in first 10m
  - Max loss (~ 30dB @ 30m) will usually knock out a satellite's signal
- Low elevation satellites suffer the worst blockage. This means that poor vertical position quality (high VDOP) is most common.





****Curve depends on the tree species***

Hardware needed to survey a forest is compact and cheap.

Software to analyze it is not available commercially, though.

Research Product

Method to survey foliage attenuation

What is needed:

1. A lidar survey of the area
2. A GPS unit that can report satellite number and signal strength
3. A sidecar processor to store the readings

Sensor: uBlox M8T

Processor: Arduino Teensy

Compact ~size of a pack of chewing gum

Inexpensive ~$400

Solver: RTKLIB, custom C++ and Python

Raycasting: Point Cloud Library, custom C++ and Python

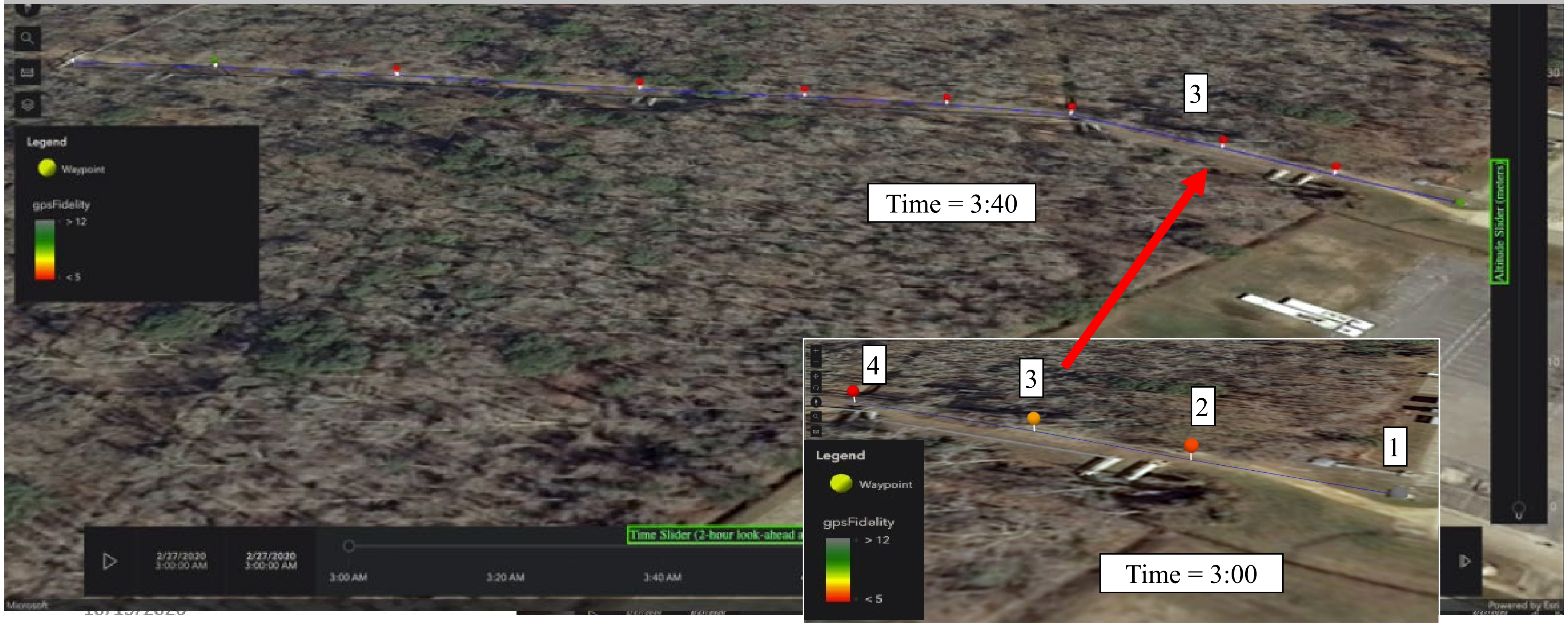
Image credit: NASA

Research Product

Prototype GPS fidelity calculator

How does the number of unobstructed GPS satellites change over 2 hours?

At waypoint $\boxed{3}$, the satellite count changes from high (foreground image) to dangerously low (background image).



# Satellites	
Red	*≤ 5*
Orange	*6-7*
Yellow	*8-9*
Green	*10-11*
Grey	*≥ 12*

Summary

This work was motivated by unexplained GPS loss during corona detection test flights over transmission lines

Computing the physics of GPS loss is a 2020's development

Three examples of computing GPS quality

(Buildings only, Buildings + trees, Trees only)

There is a characteristic attenuation vs. foliage depth curve

Conclusion

- Flight ranges in forests can be surveyed to calibrate the severity of GPS attenuation
- It is possible to forecast GPS navigation fidelity in urban and arboreal canyons

Thank you!

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BACKUP

Example 3. Mostly trees

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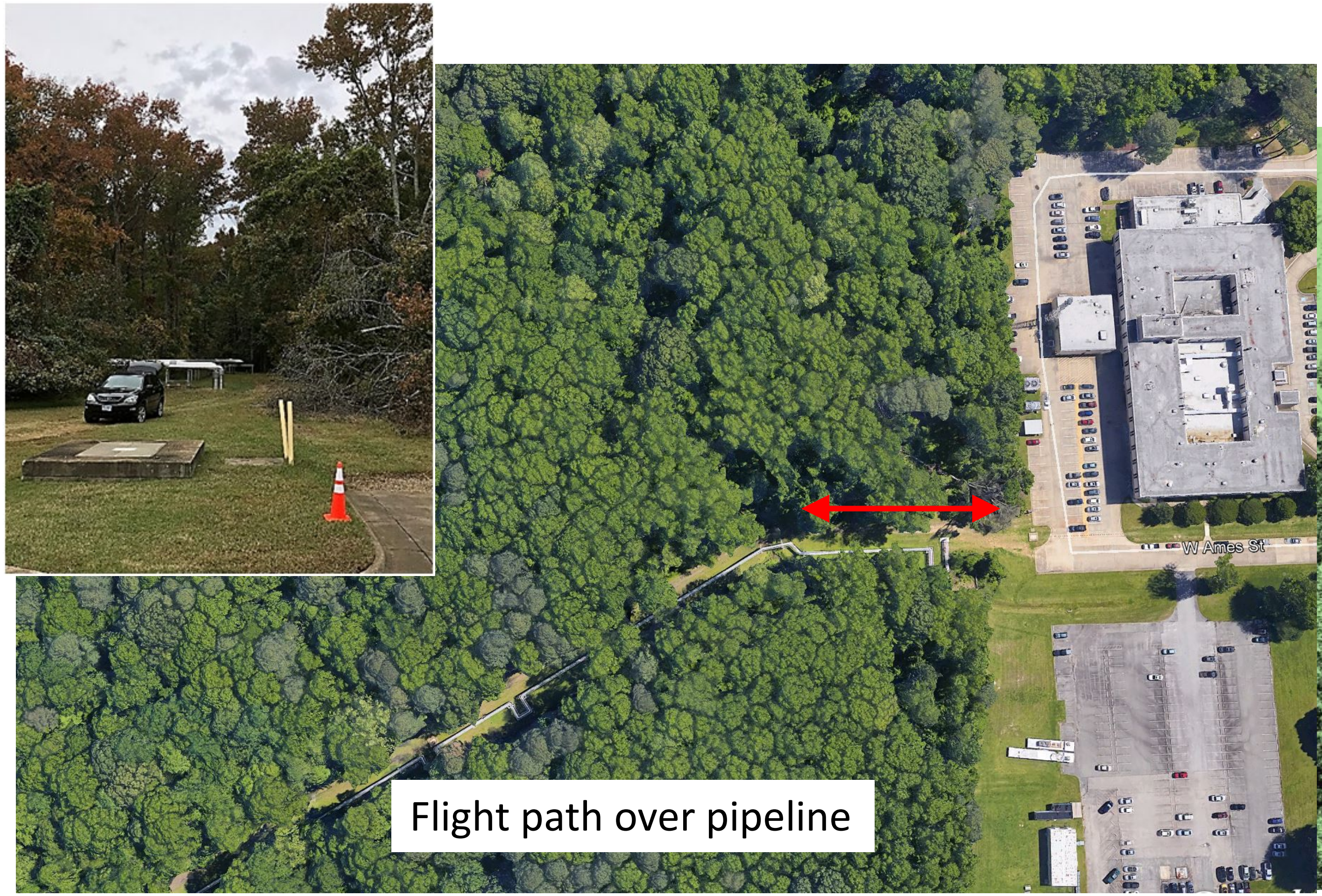

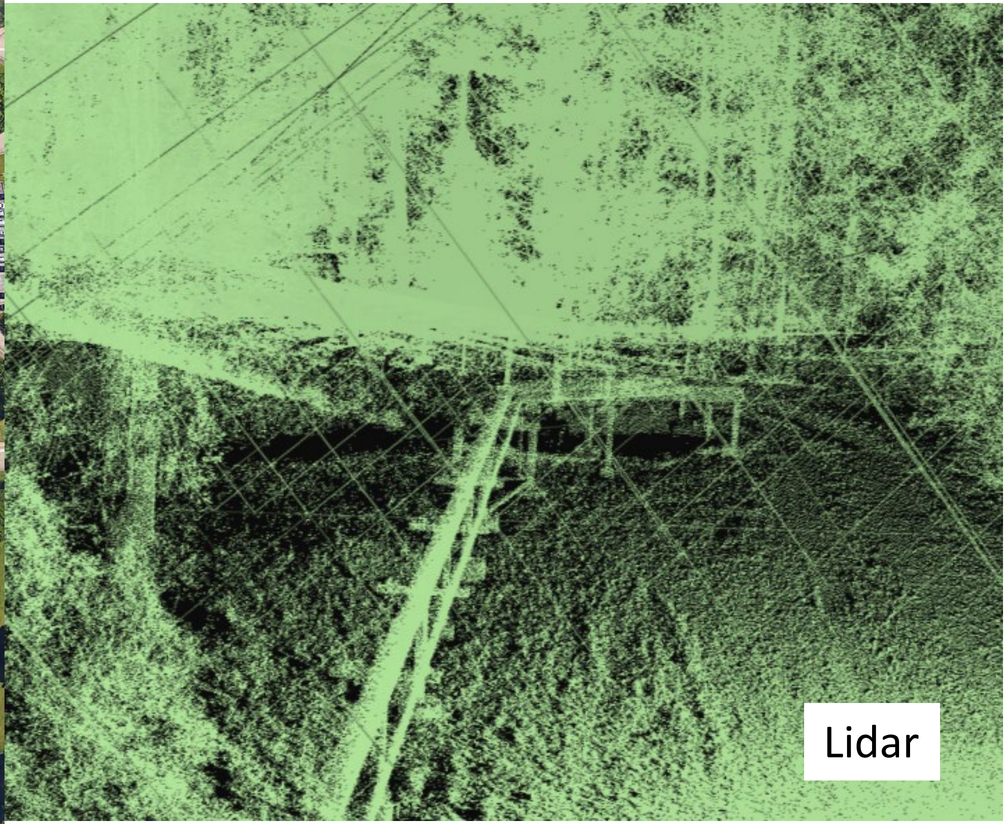

Map data: © 2021 Google Earth (Landsat, Copernicus); Image credit: NASA