Volume Raycasting of GNSS Signals through Ground Structure Lidar for UAV Navigational Guidance and Safety Estimation -- Video

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Paper #3604837, GNC-49, Aircraft GNC VII: Guidance and Path Control

AIAA Scitech 2022 January 3-7, 2022

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Outline - Volume Raycasting of GPS - *Video Version*

- Brief overview of the physics of GPS degradation and state of the art
- GPS quality investigated at two flight ranges (video)
- Discovery: the attenuation vs. foliage-depth curve
- A survey method for heavily wooded flight ranges

Conclusions

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

We are grateful to many NASA Langley colleagues for discussions and assistance in the course of this multi-year development effort, including:

- LaRC GIS Group
- Scott Dorsey, Robert McSwain and Steve Young (GNSS); Russell Gilabert (RTKLIB); Sharon Graves, Maria Consiglio and John Koelling (program support). This work was performed with support from the NASA Unmanned Traffic Management program and System Wide Safety program.

At low altitudes, GPS degradation is all too common

Computing the underlying physics is a 2020's development

UAS navigation is often hindered by degraded GPS position quality. This is caused by

1. Blockage and reflection by buildings
2. Blockage and attenuation by foliage

A useful GPS quality calculator must compute the physics rapidly and realistically using detailed surveys of ground structures

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

- Building blockage is addressed by all three
- Foliage blockage is addressed by one (this report)

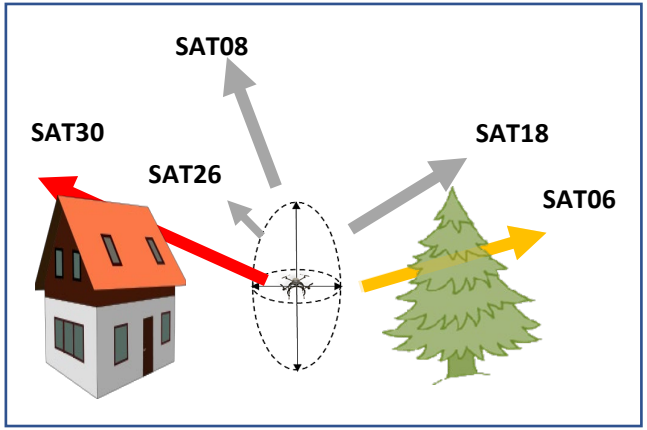


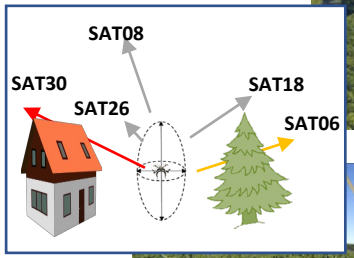
Fig. 1 Tracing the ray blockage from a UAS to five orbital satellites. The left ray is completely blocked (red), the right ray is attenuated (yellow), while the remainder (grey) are free of intersection with ground structures. ***©Graphics: NASA, NOAA, USDA***.

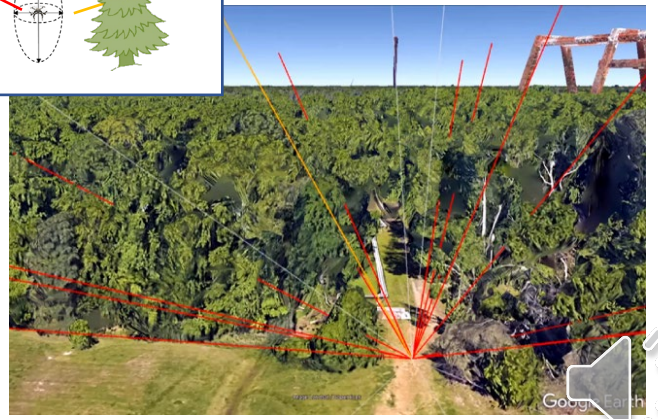
1. F. van Diggelen, *End Game for Urban GNSS: Google's Use of 3D Building Models*, Inside GNSS, 2021.
2. E. Dill et al., *A Predictive GNSS Performance Monitor for Autonomous Air Vehicles in Urban Environments,* ION GNSS+ 2021, 2021
3. A. Moore et al., *Volume Raycasting of GNSS Signals through Ground Structure Lidar for UAV Navigational Guidance and Safety Estimation,* AIAA Scitech, 2022

Visualize GPS fidelity at two sites

1. **Lunar Lander Research Facility**

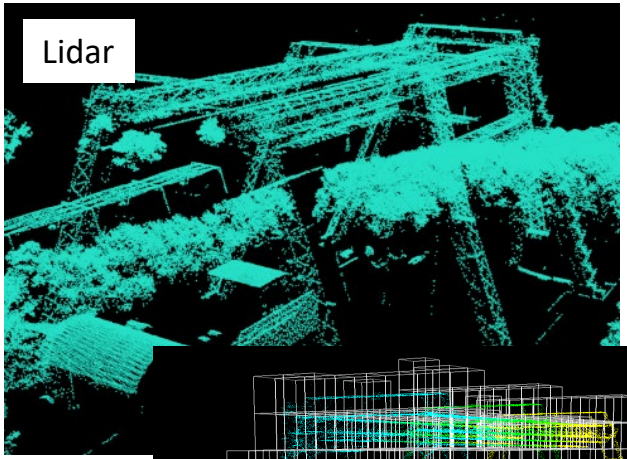
2. **Arboreal canyon** (pipeline corridor)

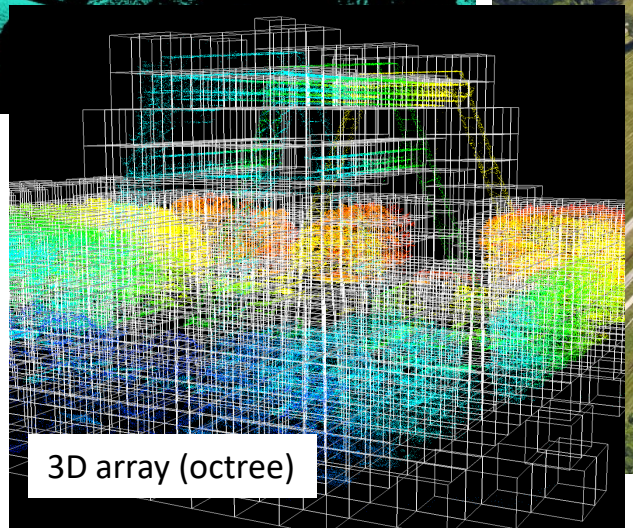




Site 1. NASA Langley Lunar Lander Research Facility

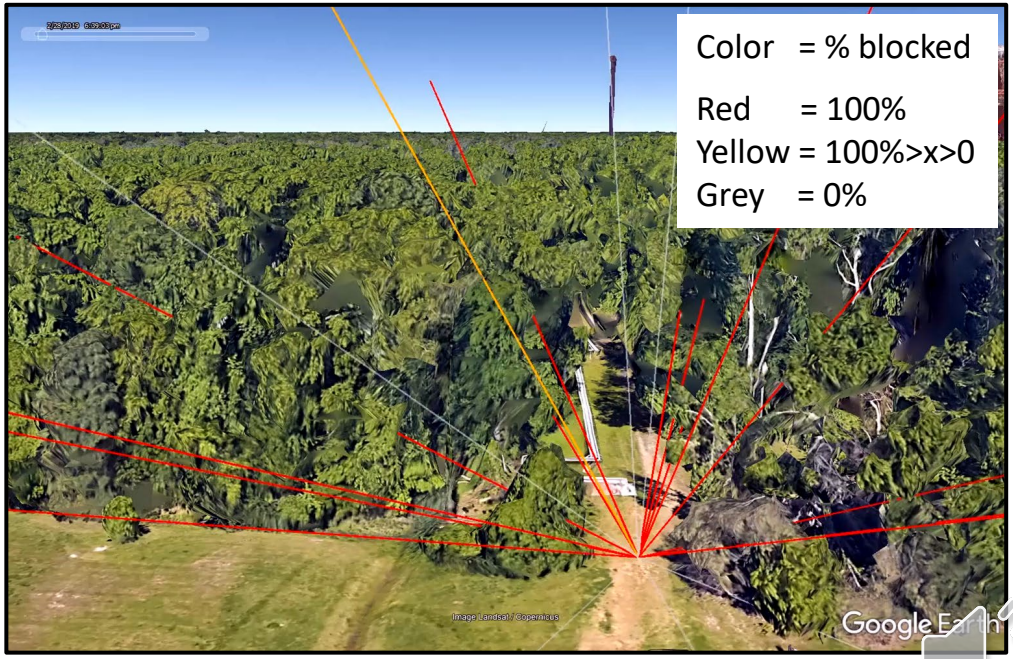
March 2018 flight.
We assumed buildings block 100% and 5m of foliage block 100% of the ray.





Site 2. Arboreal canyon with steam pipeline

February 2019 flight at 15m altitude.
We assumed buildings block 100% and 5m of foliage block 100% of the ray.



What is the *real* attenuation by trees?

Up to now we assumed linear summation along the ray and nominal (20%) attenuation per meter.

- Is GPS (c/N0) attenuation of foliage linear with depth?
- What is the real attenuation value?

To compare satellite signal strength to foliage depth, we conducted research flights and recorded GPS on 14 days from November 2018 to February 2021.

- Collected 55 recordings, yielding thousands of signal measurements
- Varied constellation (time of day)
- Varied altitude (ground walk, flights at 5m-40m altitude)

A characteristic curve for GPS attenuation by foliage

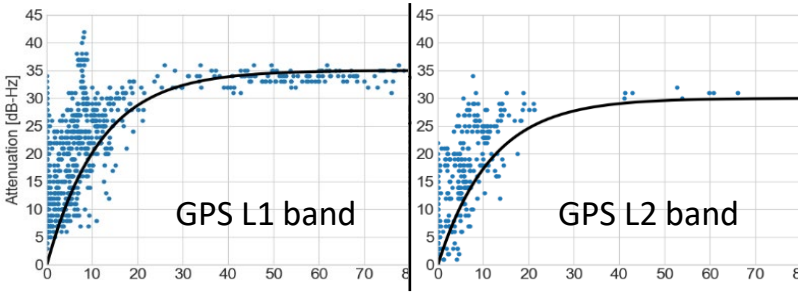
Experimental result

- 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).

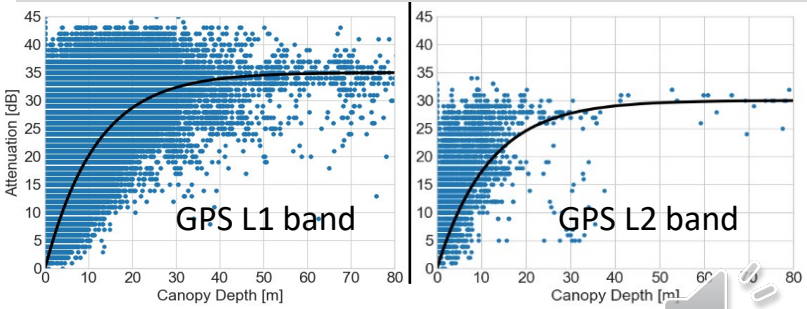
Consistent finding: results follows continuous-wave radio attenuation curve – but with 10X steeper γ (dB/m)

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

Data from a single recording



All data acquired across 2 years

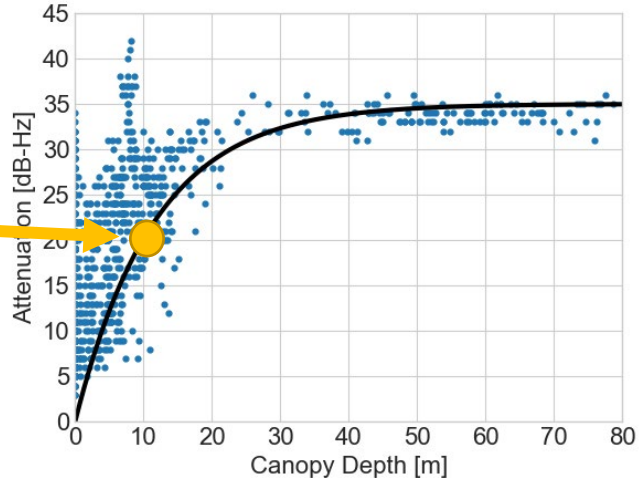


Implications for flying in arboreal canyons

What kinds of flights are impacted by foliage degradation of GPS?

- Infrastructure inspection
- Property survey
- Storm recovery
- Search and rescue

- *For this mixed hardwood canyon**
  60% of signal lost in first 10m



©Graphics: NASA

* *We expect that the curve depends on the tree species, as for continuous-wave radio attenuation*

Summary - *Video Version*

GPS quality was investigated at two flight ranges

1) Visualized GPS reception using nominal attenuation value for foliage
2) Measured actual attenuation in a series of flight experiments

There is a characteristic GPS attenuation vs. foliage-depth curve ★

- Infrastructure inspection
- Storm recovery
- Property survey
- Search and rescue

Conclusion

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