AUVSI Webinars

Understanding GPS Navigation in Contested Environments

Speaker:

- **Ted Driver –** Head of Analytics, OneSky

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Understanding GPS in Contested Environments

Ted Driver
Head of Analytics, OneSky
April 22, 2020

Overview

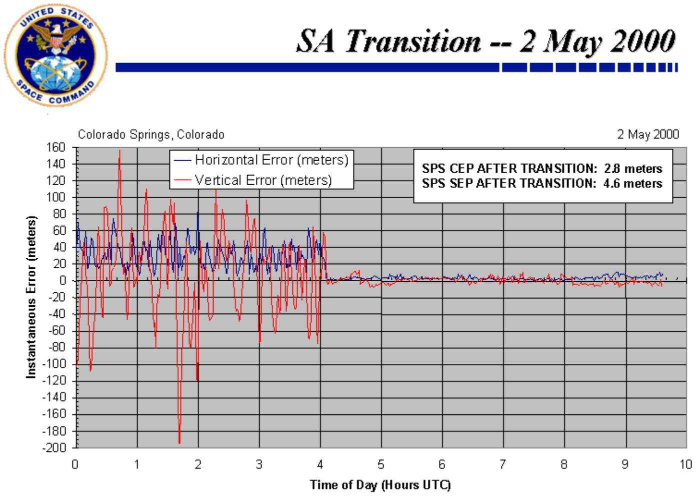
- Understanding GPS position error
- Dilution of precision and user range errors
- Physical and radio visibility
- Terrain heights and field results
- Mitigation techniques
- Alternative navigation technologies

Introduction - Ted Driver

- Architect and developer of the OneSky analytical SDSP services
- Navigation SME and algorithm developer at Analytical Graphics Inc.
- Lead analyst at the GPS Operations Center (GPSOC)

Precise location is ubiquitous

- Civilian access to precise location since May 2, 2000
- GPS receivers turned into chips
  - Location services in every type of device now
- Industries now rely on knowing location
  - UAM/UAS systems built upon this



Understanding your Position Error

$$\vec{r}_t = \vec{r}_m + \Delta\vec{r}$$

Position measurements have errors

$$\Delta\vec{r} = (\boldsymbol{G}^T\boldsymbol{G})^{-1}\boldsymbol{G}^T \cdot \Delta\vec{\rho}_c$$

GPS measurement errors result from satellite geometry and errors in ranging to each satellite

$$\boldsymbol{G} \equiv \begin{bmatrix} \hat{L}_{1x} & \hat{L}_{1y} & \hat{L}_{1z} & 1 \\ \hat{L}_{2x} & \hat{L}_{2y} & \hat{L}_{2z} & 1 \\ \cdots & \cdots & \cdots & \cdots \\ \hat{L}_{jx} & \hat{L}_{jy} & \hat{L}_{jz} & 1 \end{bmatrix}$$

$$\mathbf{H} = (\boldsymbol{G}^T\boldsymbol{G})^{-1} \qquad \vec{\mathrm{U}} = \boldsymbol{G}^T \cdot \Delta\vec{\rho}_c$$

$$\Delta\vec{r} = \mathbf{H} \cdot \vec{\mathrm{U}}$$

The quality of your position measurement is based on this product

Reducing your error

$$\Delta\vec{r} = \mathbf{H} \cdot \vec{\mathrm{U}}$$

H is the Dilution of Precision (DOP) matrix

unitless – a multiplier

U is the User Range Error (URE) vector

Reducing the magnitude of H or U or both will reduce your position error

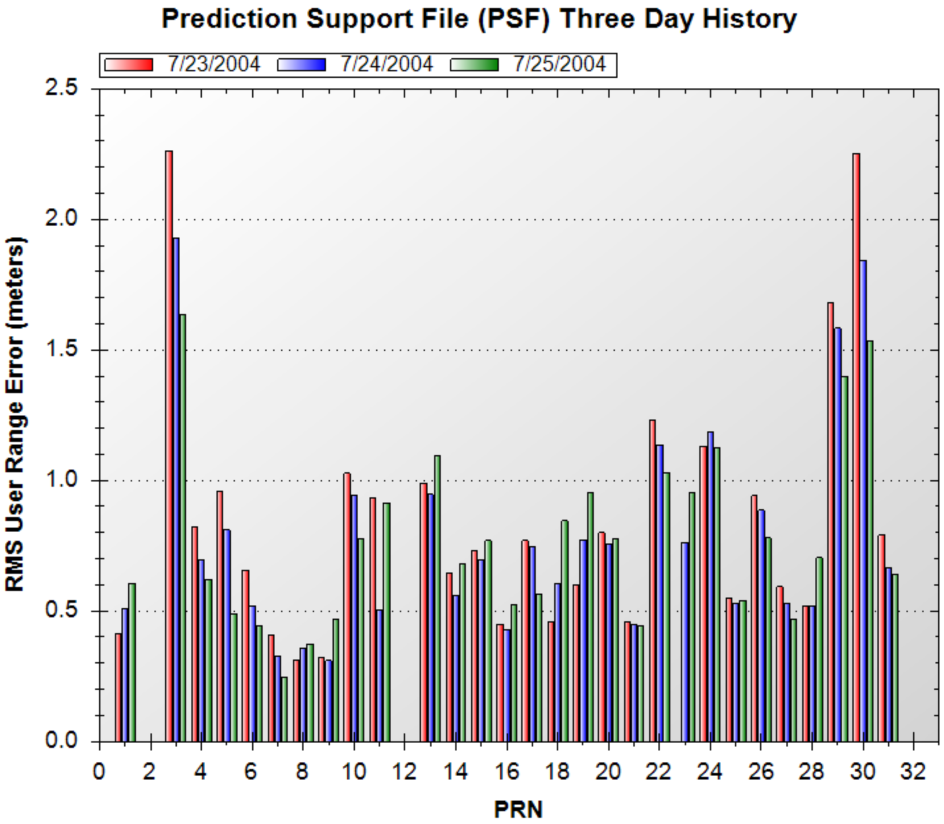
User Range Errors

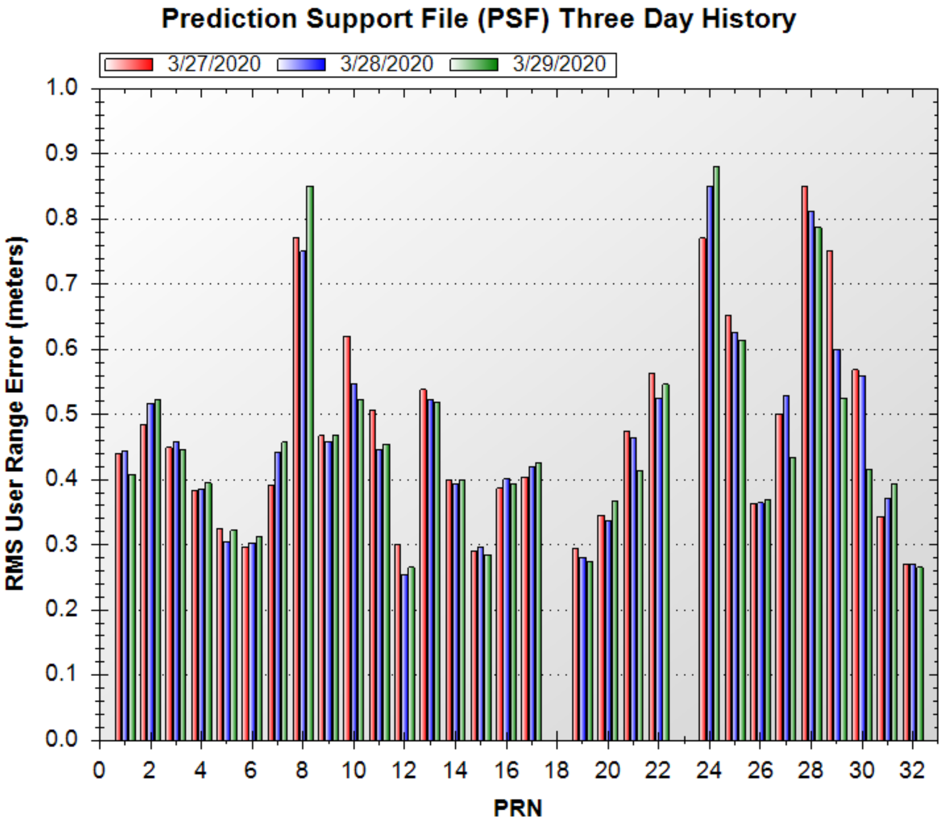
- Signal in space errors (0.5 - 3 meters)
  - Satellite ephemeris and atomic clock prediction errors
  - Control segment controls these
- Atmospheric mis-modeling
  - Ionospheric errors for single frequency users, or scintillation (4+)
  - Tropospheric errors for thick atmosphere, close to the horizon (0.7+)
- Multi-path errors (0-1.5+)
  - In environments with signal reflection issues
- Receiver errors (0.8+)
  - Noise

RMS URE error

6 - 9+ meters

RMS GPS Signal In Space URE





Dilution of Precision - **H**

$$\boldsymbol{G} \equiv \begin{bmatrix} \hat{L}_{1x} & \hat{L}_{1y} & \hat{L}_{1z} & 1 \\ \hat{L}_{2x} & \hat{L}_{2y} & \hat{L}_{2z} & 1 \\ \cdots & \cdots & \cdots & \cdots \\ \hat{L}_{jx} & \hat{L}_{jy} & \hat{L}_{jz} & 1 \end{bmatrix}$$

$$\mathbf{H} = (\boldsymbol{G}^T \boldsymbol{G})^{-1}$$

$$\boldsymbol{H} = \begin{bmatrix} H_{11} & H_{12} & H_{13} & H_{14} \\ H_{21} & H_{22} & H_{23} & H_{24} \\ H_{31} & H_{32} & H_{33} & H_{34} \\ H_{41} & H_{42} & H_{43} & H_{44} \end{bmatrix} \begin{matrix} X \\ Y \\ Z \\ T \end{matrix}$$

$$\begin{matrix} X & Y & Z & T \end{matrix}$$

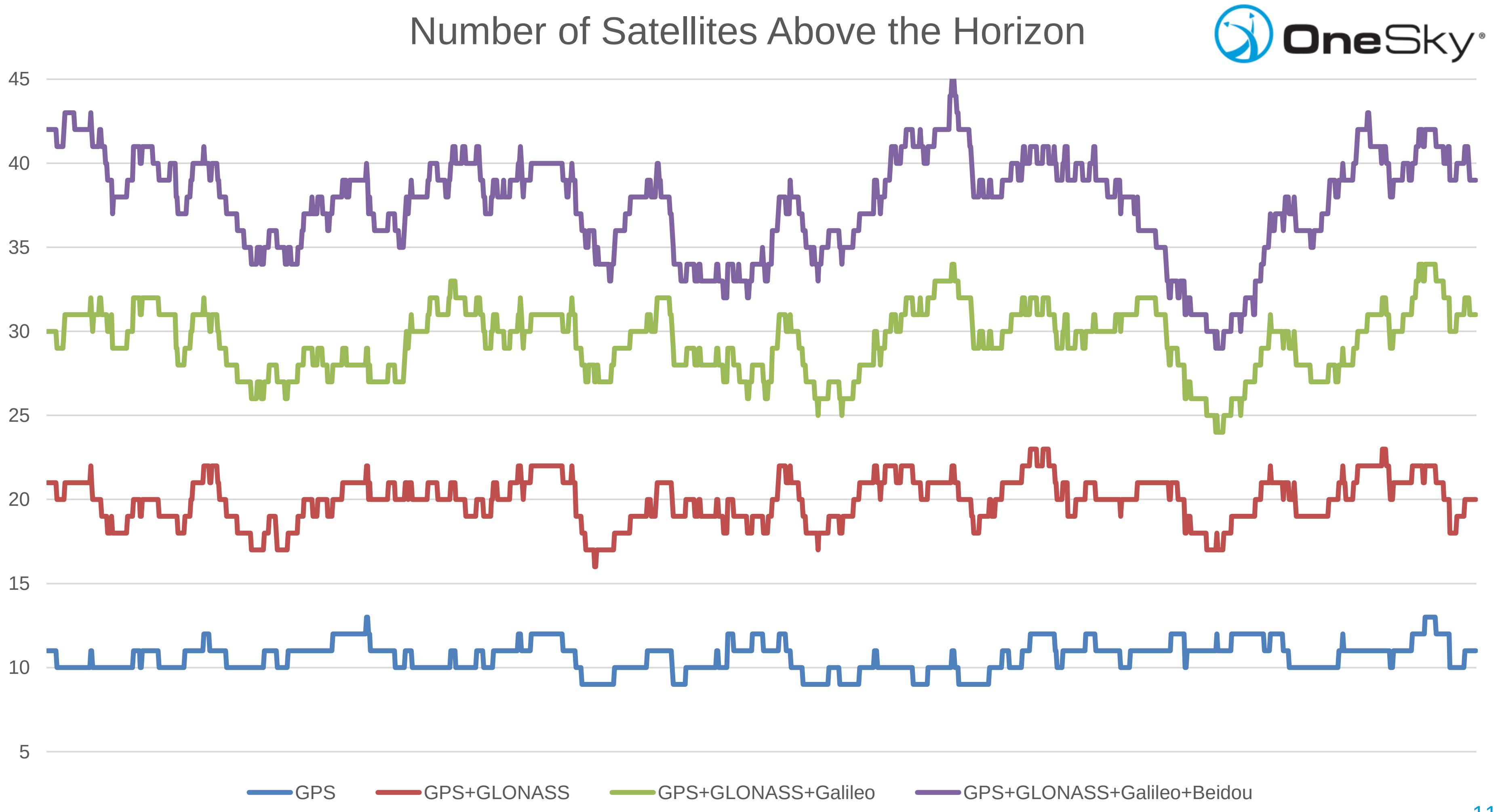
$$HDOP = \sqrt{H_{11}^2 + H_{22}^2}$$

$$VDOP = \sqrt{H_{33}^2}$$

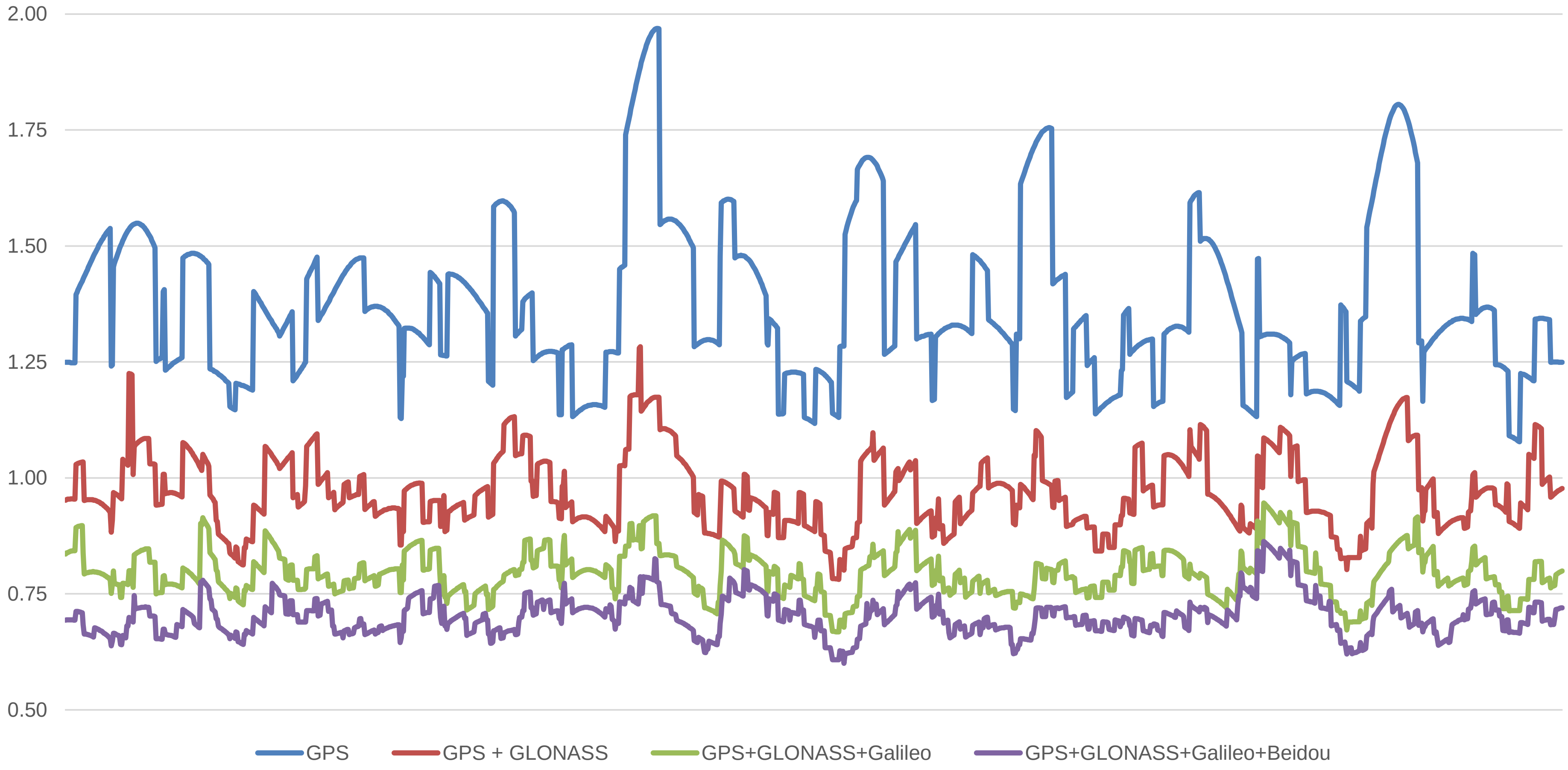
$$PDOP = \sqrt{H_{11}^2 + H_{22}^2 + H_{33}^2}$$

$$TDOP = \sqrt{H_{44}^2}$$

$$GDOP = \sqrt{H_{11}^2 + H_{22}^2 + H_{33}^2 + H_{44}^2}$$


Number of Satellites Above the Horizon
OneSky
45
40
35
30
25
20
15
10
5
GPS
GPS+GLONASS
GPS+GLONASS+Galileo
GPS+GLONASS+Galileo+Beidou

Multi-Constellation Geometric Dilution of Precision (GDOP)



Visibility

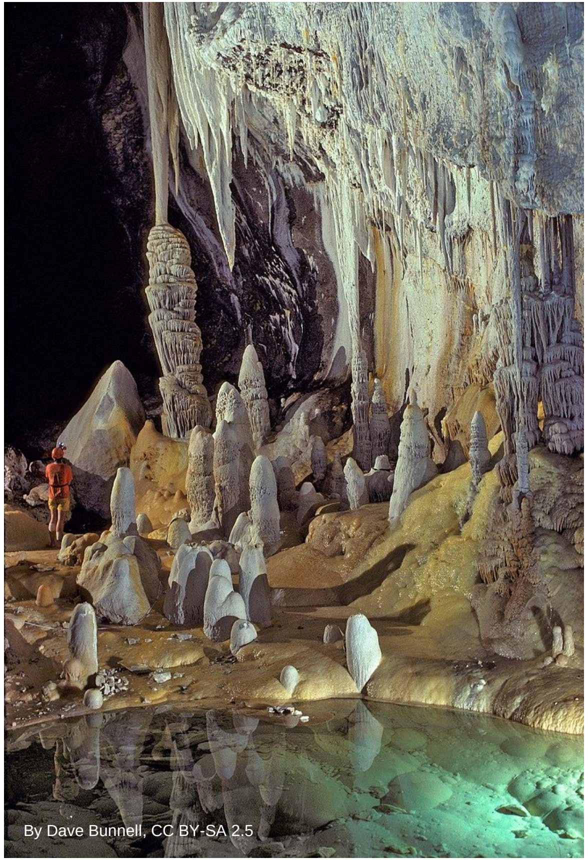
Reducing the number of satellites in **G**

- Increases the magnitude of **H**, which
- Increases your error

So, what will reduce the number of satellites visible to your device?

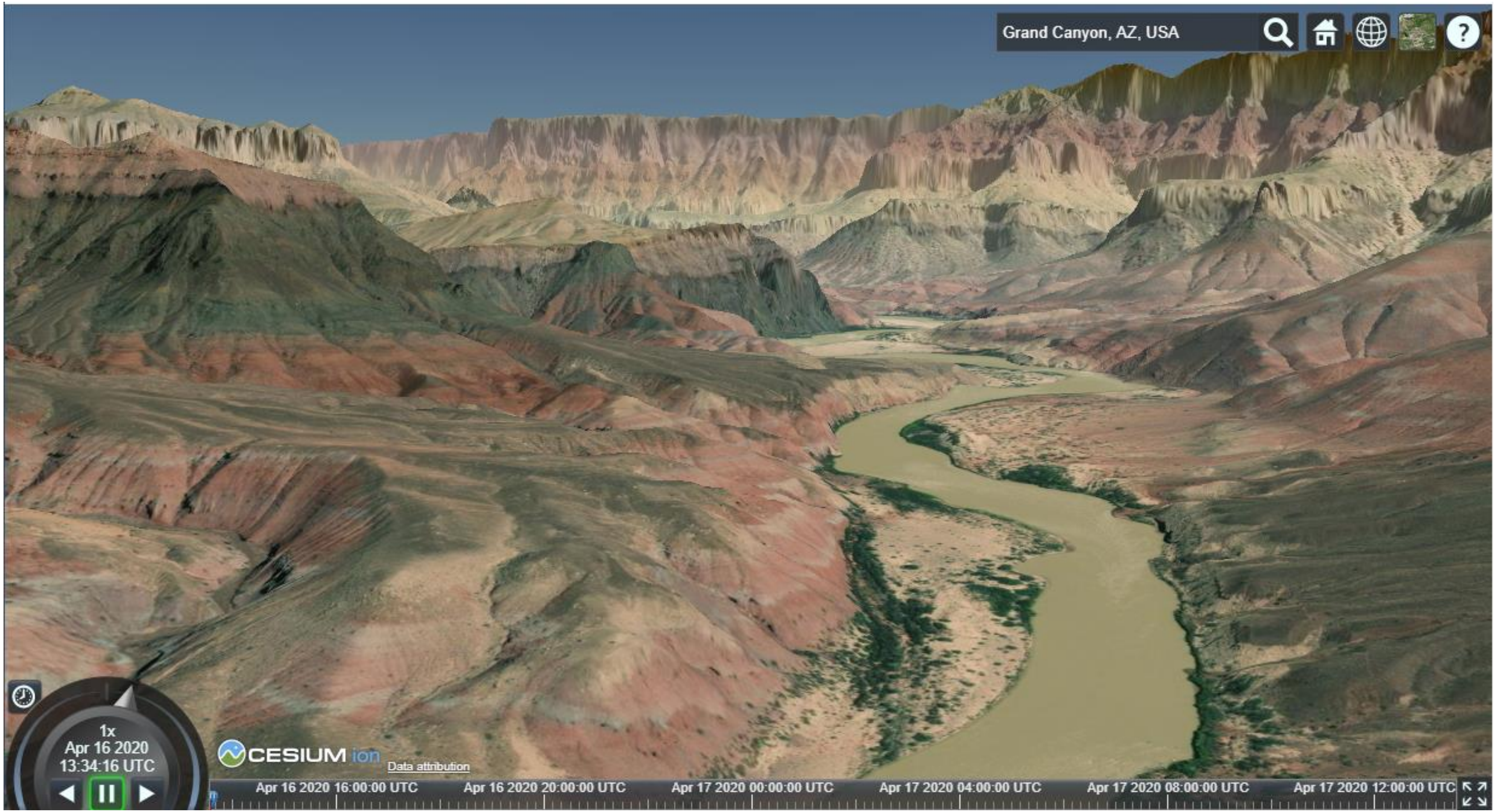
Physical Visibility

DenisTangneyJ/Getty Images

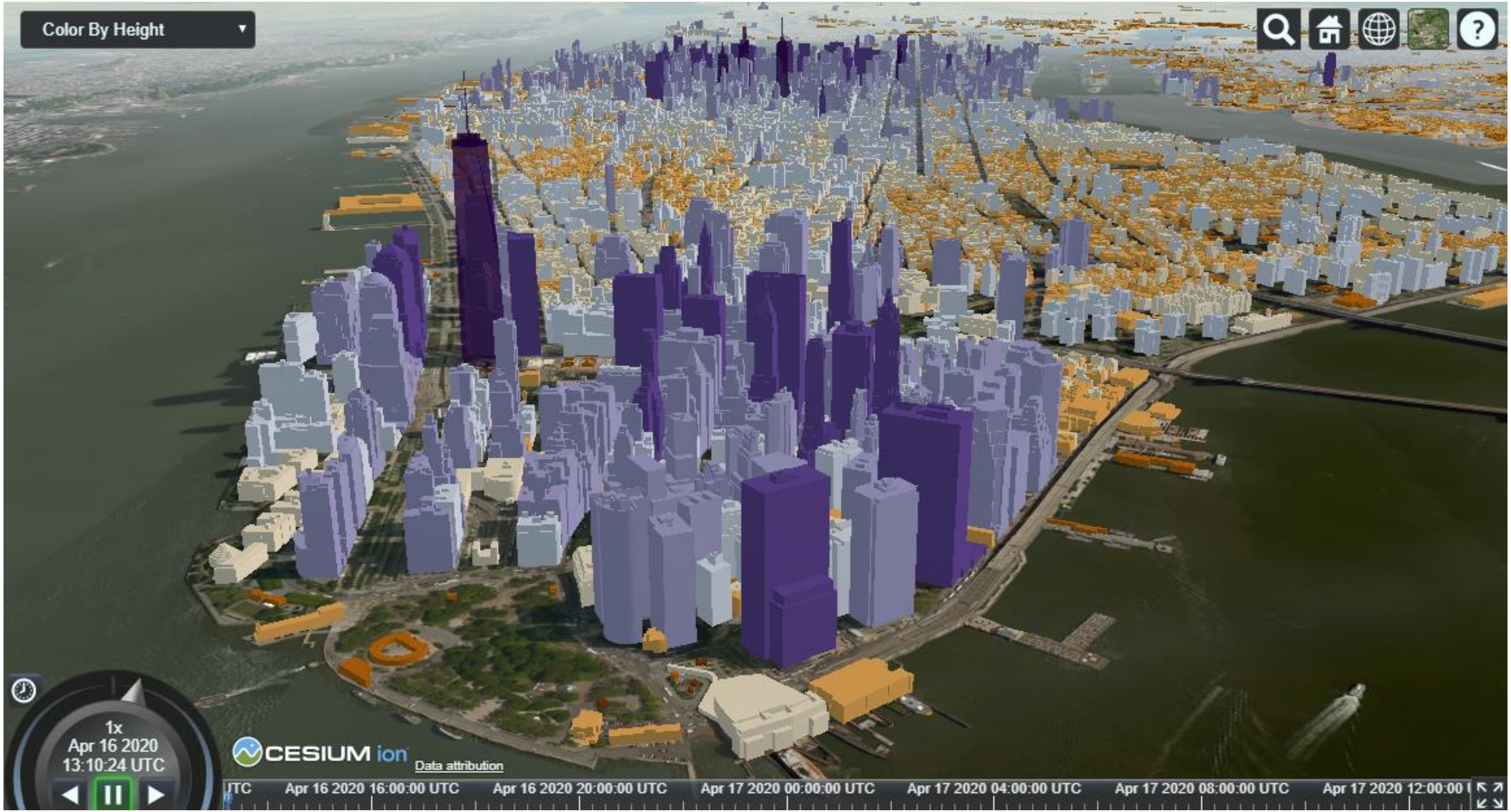


By Dave Bunnell, CC BY-SA 2.5

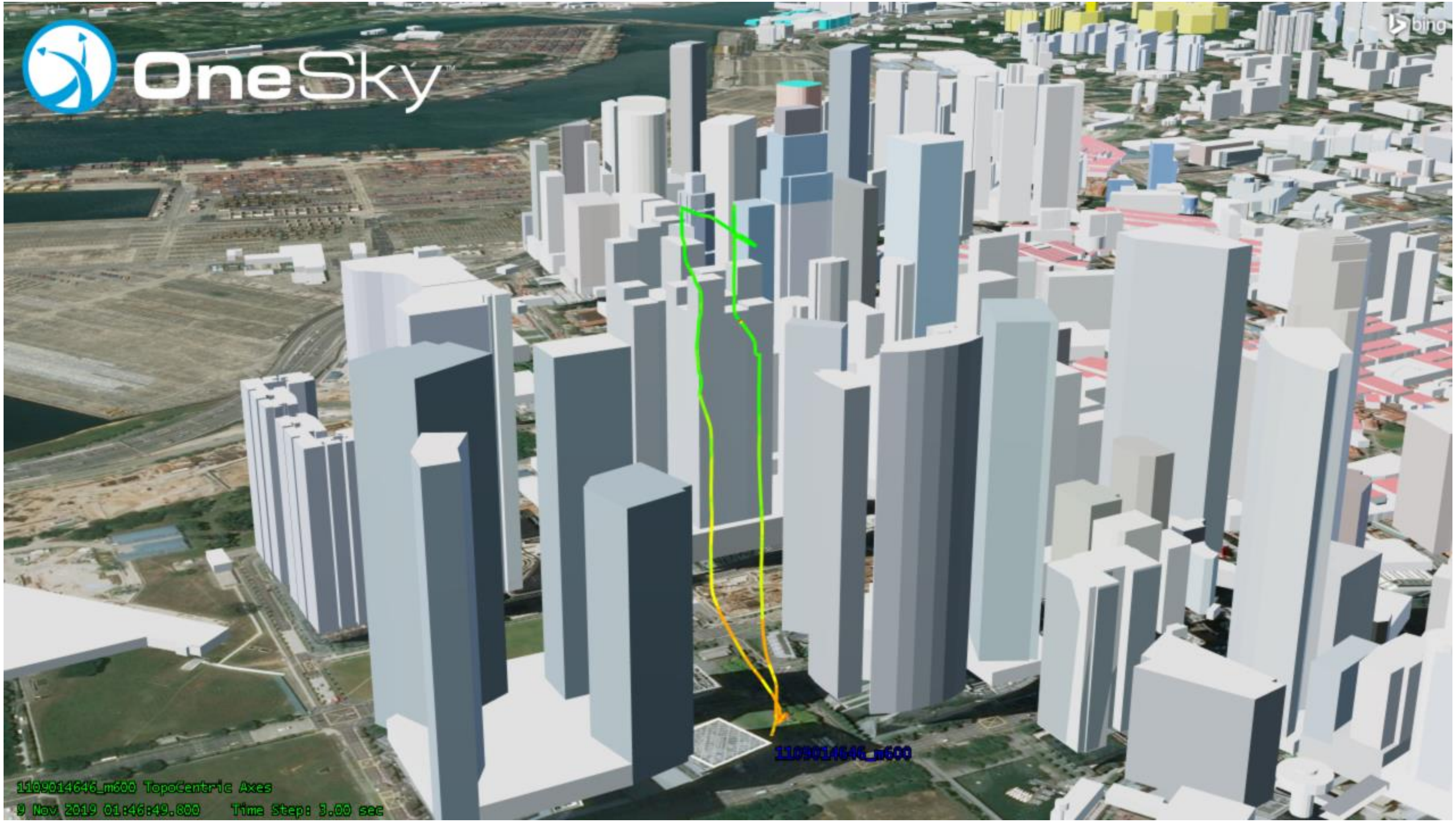
Physical Visibility



Physical Visibility



Singapore Test flights



Singapore Test flights

Radio Visibility

Signals must be received with enough power to demodulate PRN code and data

- Typical value for tracking is 35 dB-Hz

When signals are not tracked, they are not part of the **G** matrix

OneSky®

Radio Visibility

GPS signal strength is below the noise floor

Transmitted signal:

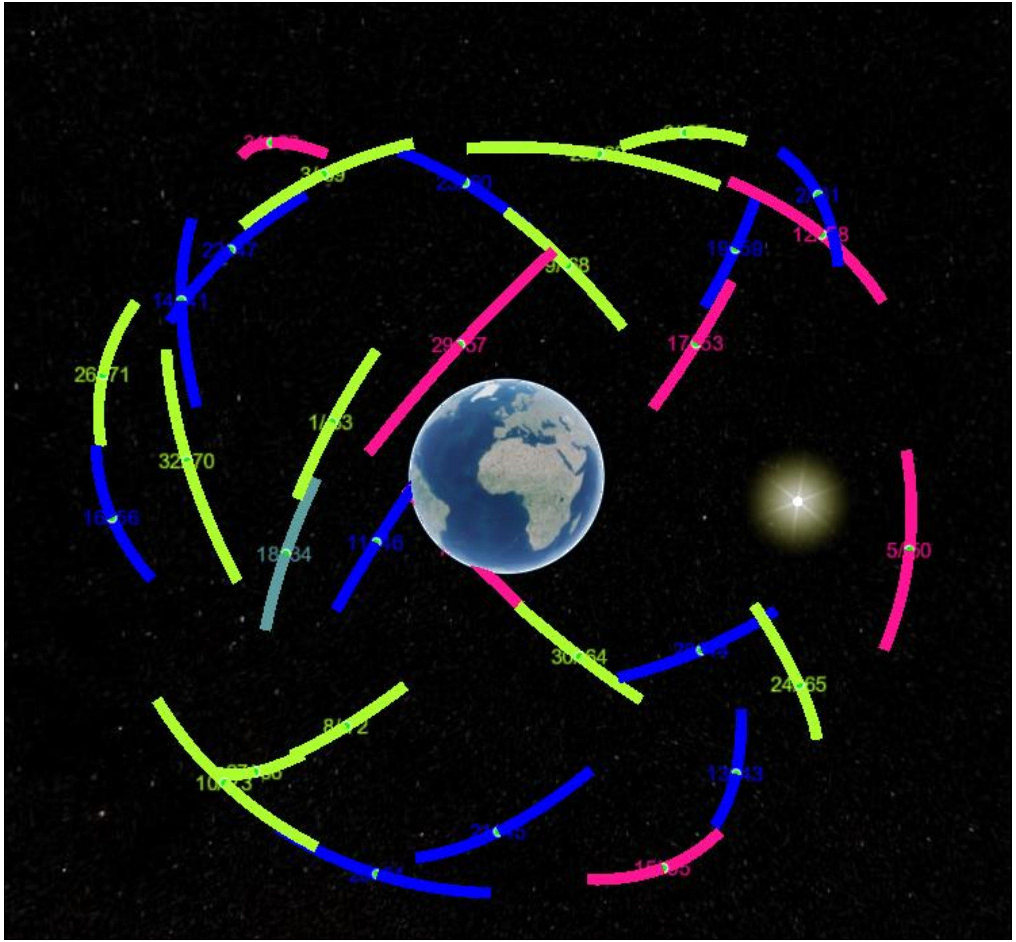
- 25 watts

Distance:

- 20200 km

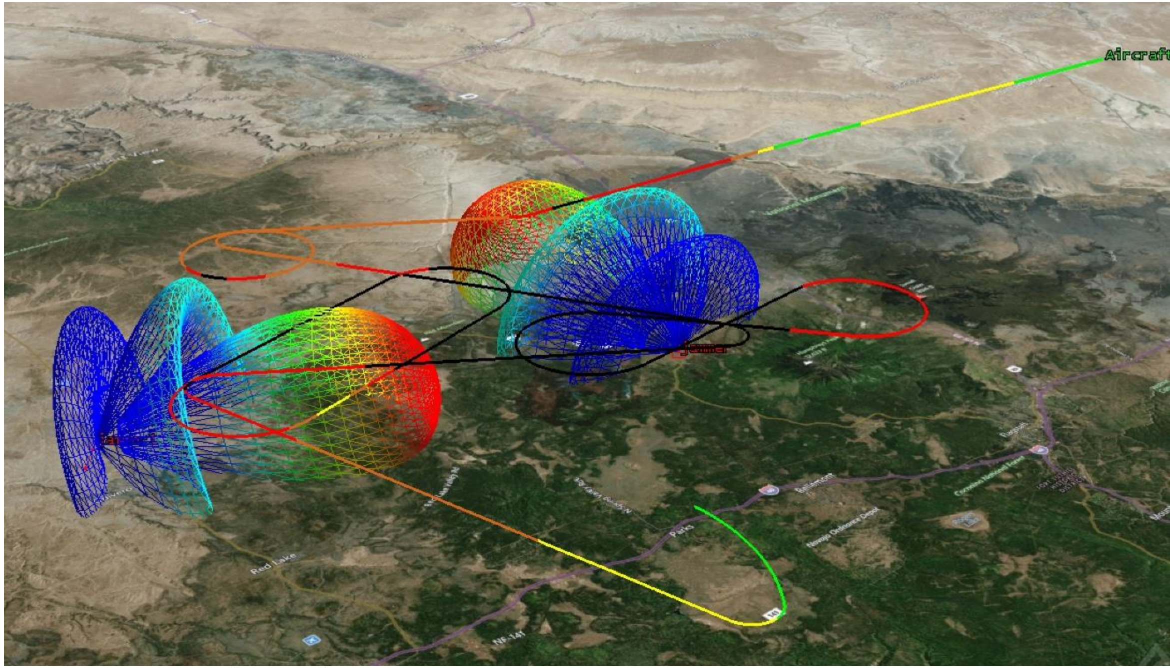
Power at the Earth

- -157 dBW



Radio Visibility

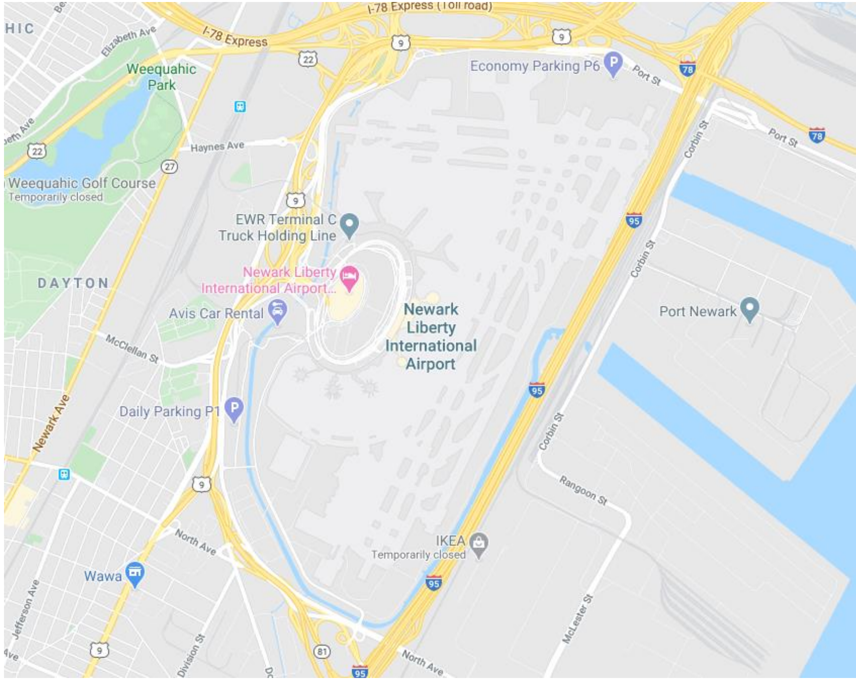
GPS signals are easily jammed



1 watt jammer can disrupt GPS within 30 miles

Jamming Examples

- 2012: New Jersey construction worker

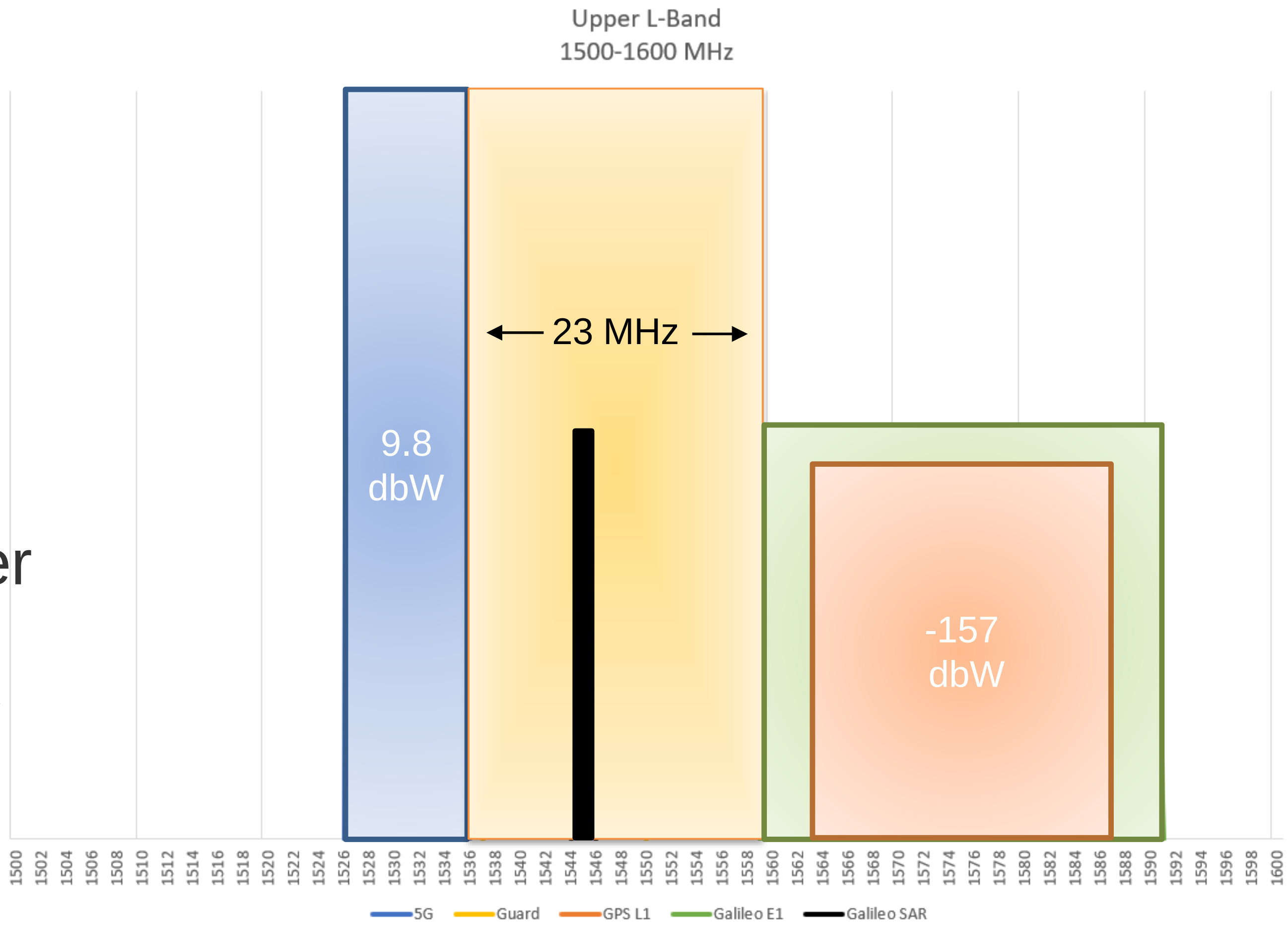


Jamming Examples

- 2012: New Jersey construction worker
- 2013-2016: 80 incidents reported
- 2019: Hong Kong drone show

Recent news

- FCC approved Ligado to broadcast 5G near GNSS frequencies
- 5G signal power ~155 million times as strong as GPS



Other Issues

- Misunderstandings can cause operational errors

Corpus Christi TCL-4 Results

Corpus Christi TCL-4 Results

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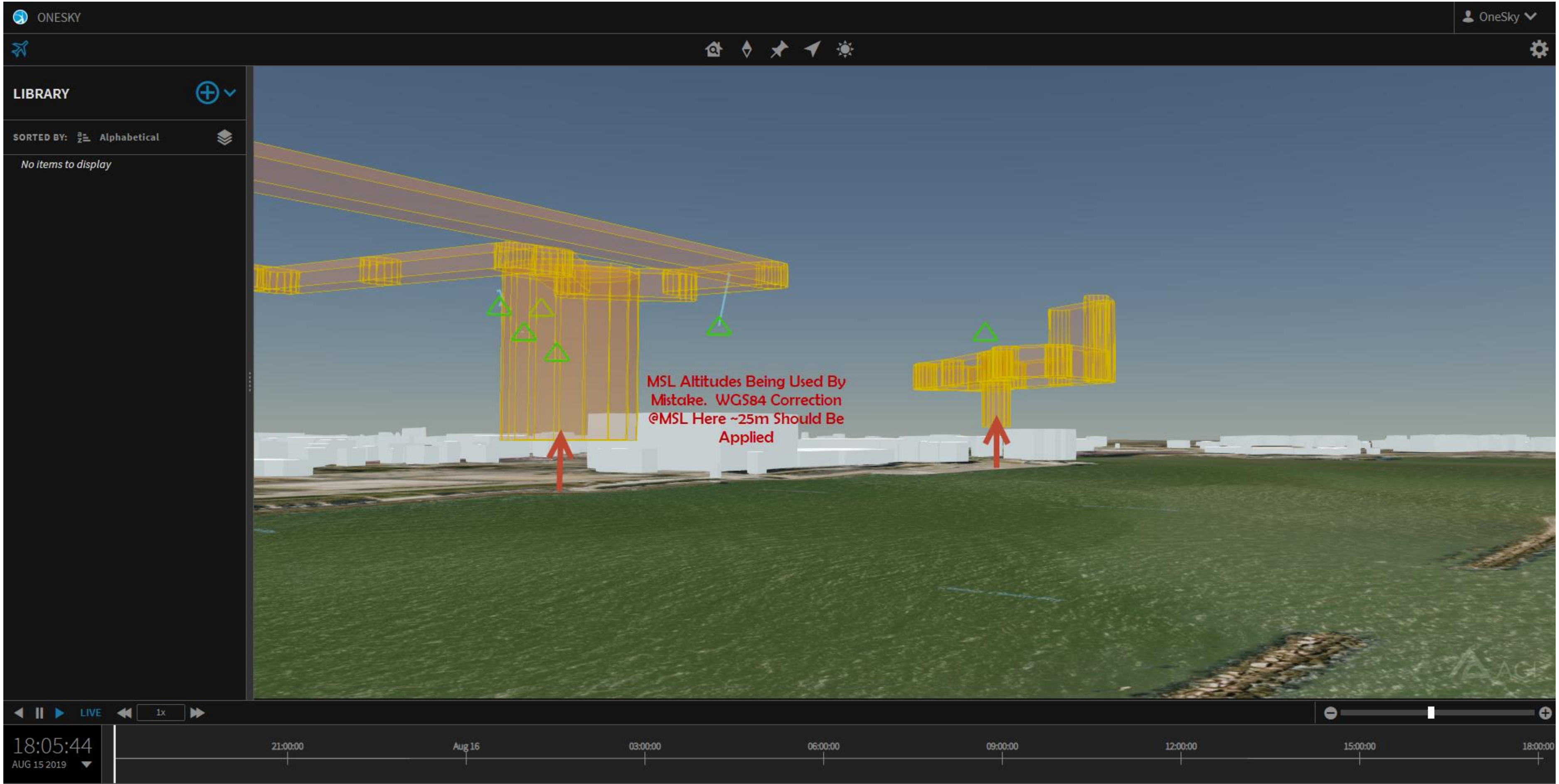
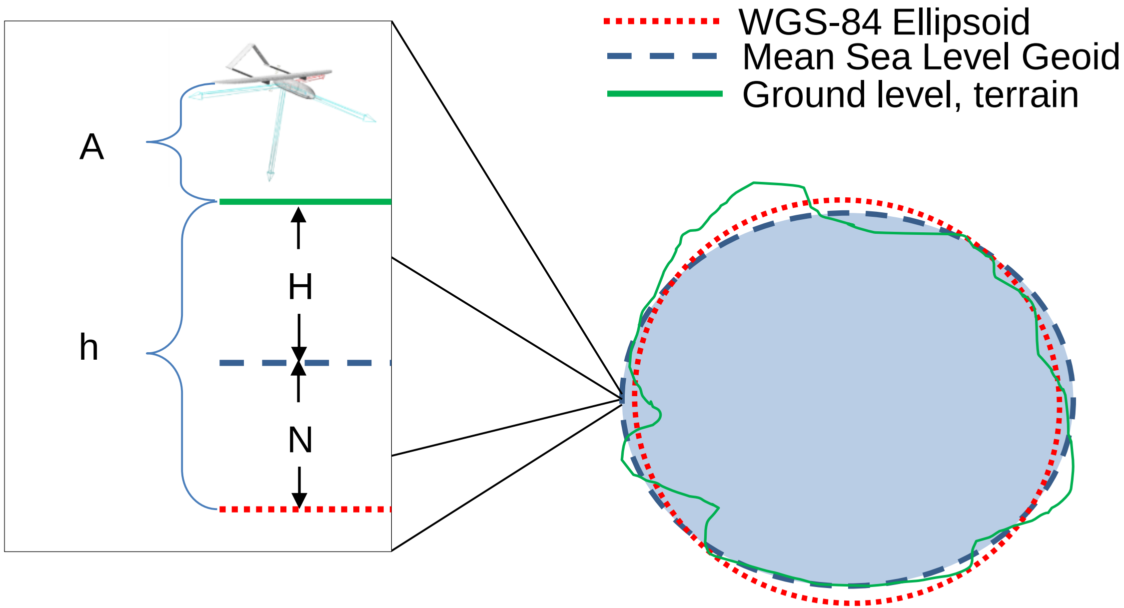


Terrain Heights and Datums



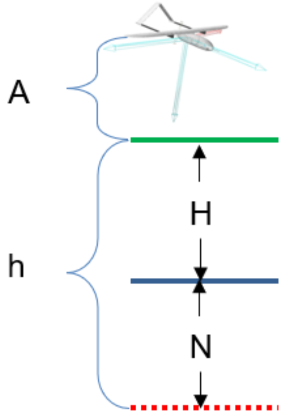
$$h = H + N$$

A = AGL height

A Height Example

From a OneSky terrain height service*:

```
h    {
N        "TerrainHeightFromWgs84": 4283.139414769325 4,
H        "MeanSeaLevelHeightFromWgs84": -16.10807761064754 8,
         "TerrainHeightFromMeanSeaLevel": 4299.247492379972 8
     }
```



You’re flying at altitude: A = 250 ft AGL

What will GPS report your altitude as?

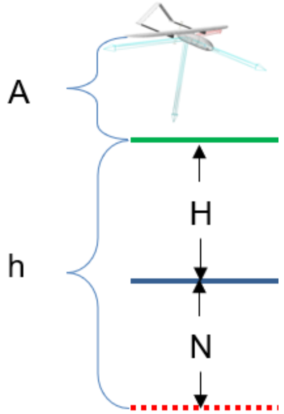
h + A = GPS altitude

*https://saas.onesky.xyz/V1/Documentation/Terrain#heights

A Height Example

From a OneSky terrain height service*:

```
    {
h       "TerrainHeightFromWgs84": 4283.1394147693254,
N       "MeanSeaLevelHeightFromWgs84": -16.108077610647548,
H       "TerrainHeightFromMeanSeaLevel": 4299.2474923799728
    }
```



You’re flying at altitude: A = 250 ft AGL

$$4283.14\ meters_{WGS-84} + \frac{250\ feet_{AGL}}{3.28084\ feet/meter} = 4359.34\ meters_{WGS-84}$$

$$4359.34\ meters_{WGS-84} - (-16.108) = 4375.45\ meters_{MSL}$$

*https://saas.onesky.xyz/V1/Documentation/Terrain#heights

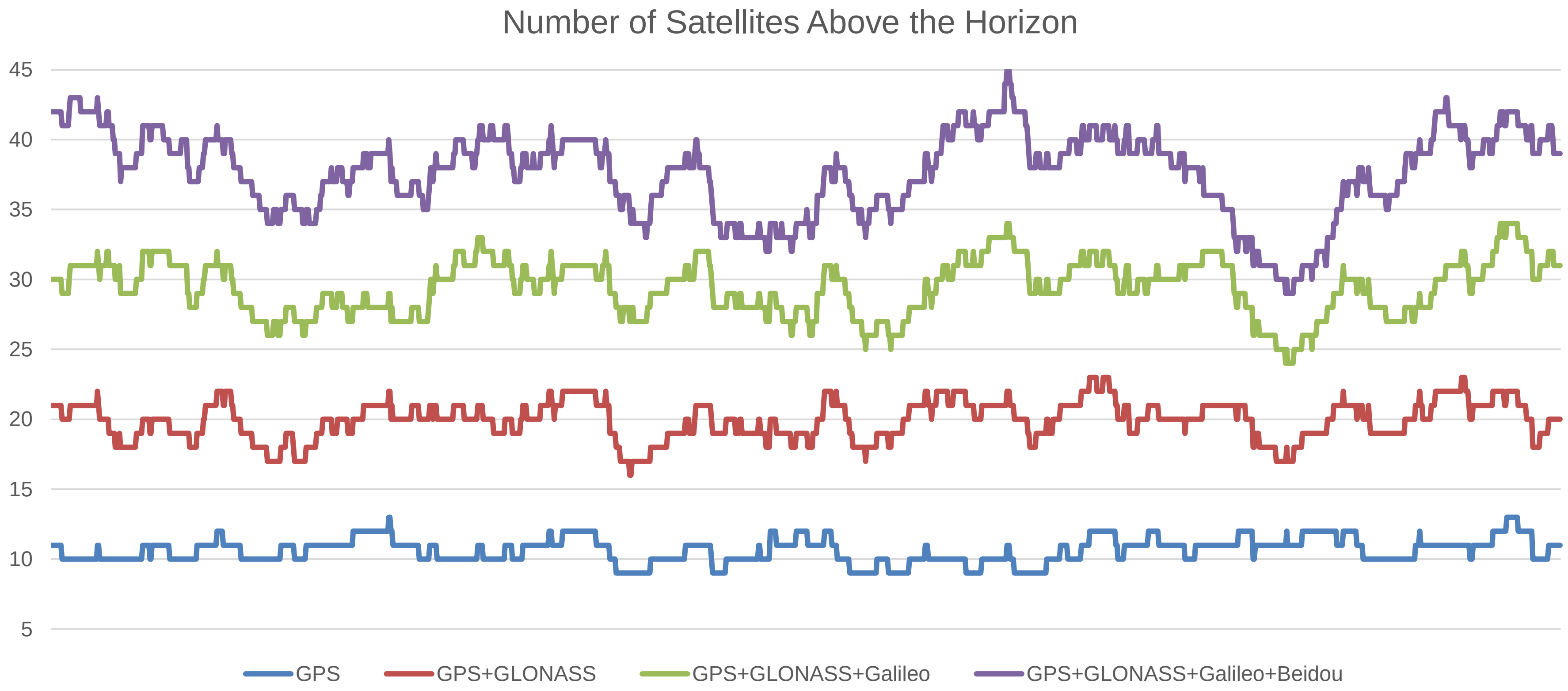
Mitigation

- Modeling and Simulation
- Strategies to increase the number of satellites in **G**
  - Terrain and jamming mitigation
- Ways to find precise locations without using GPS
  - Alternative navigation solutions

Modeling and Simulation

- Understand your situation
  - How is your mission affected?
- Apply model-based systems engineering
  - Try before you fly
  - Digital twin
  - What-if scenarios

Terrain Mitigation – more satellites



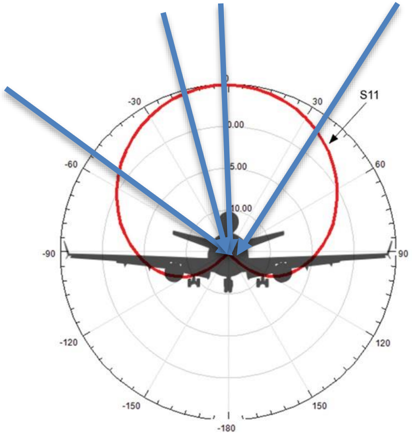
Terrain Mitigation - Assisted GPS

- Critical data downloaded in a clear environment
    - Transmitted over cell network to platform in a contested environment with GPS chip

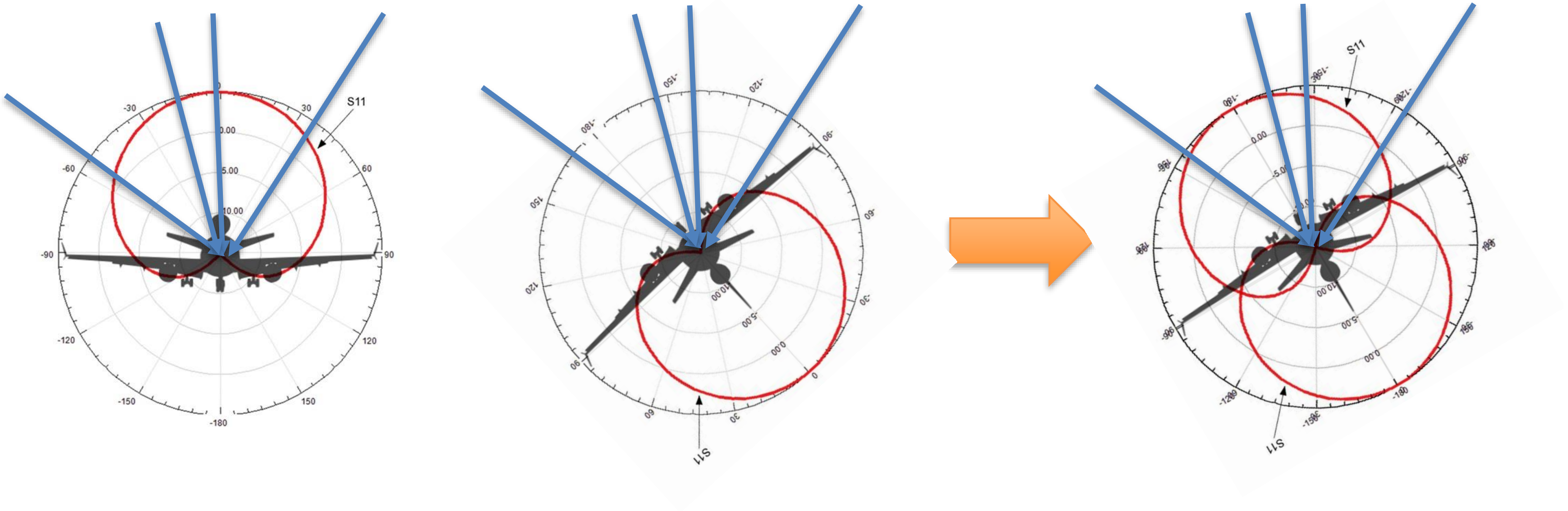
Mitigation - Real-Time Kinematic (RTK)

- RTK uses carrier-wave navigation
  - Accurate to the centimeter level
  - Needs assistance to remove ambiguities
- Base station averages position over time
  - Transmits derived errors to roving stations or UAS

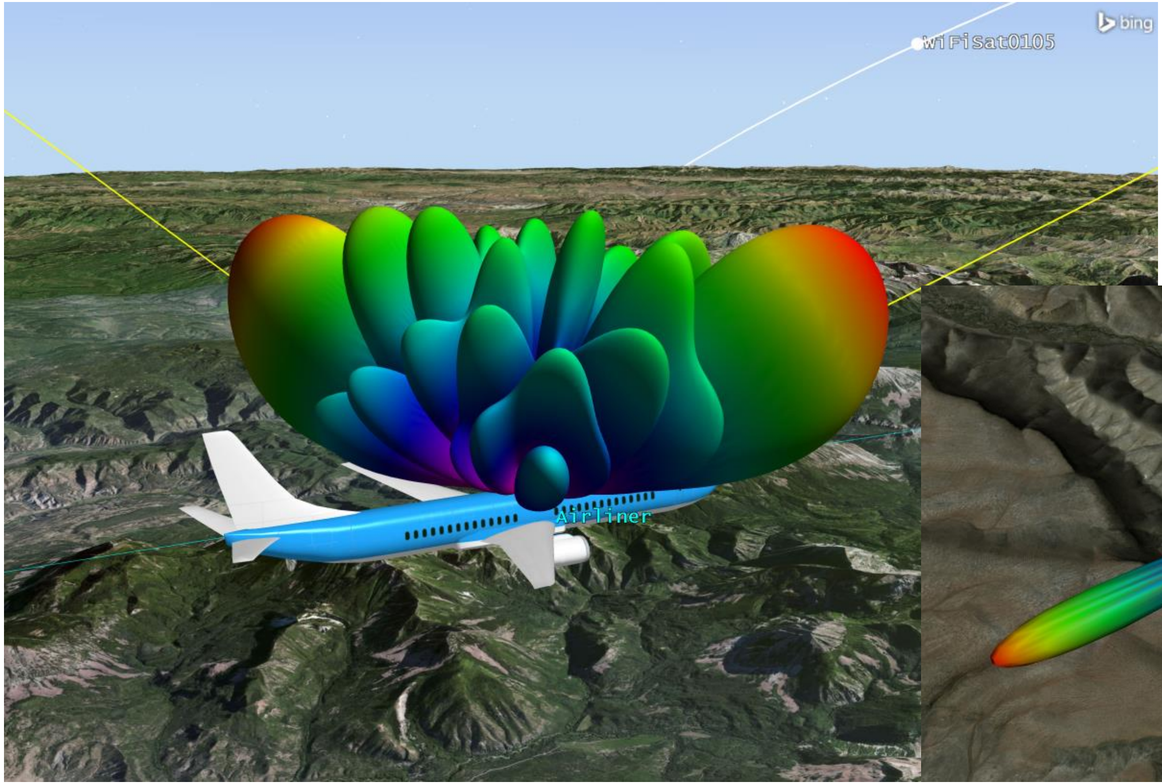
Mitigation – Antenna Gain

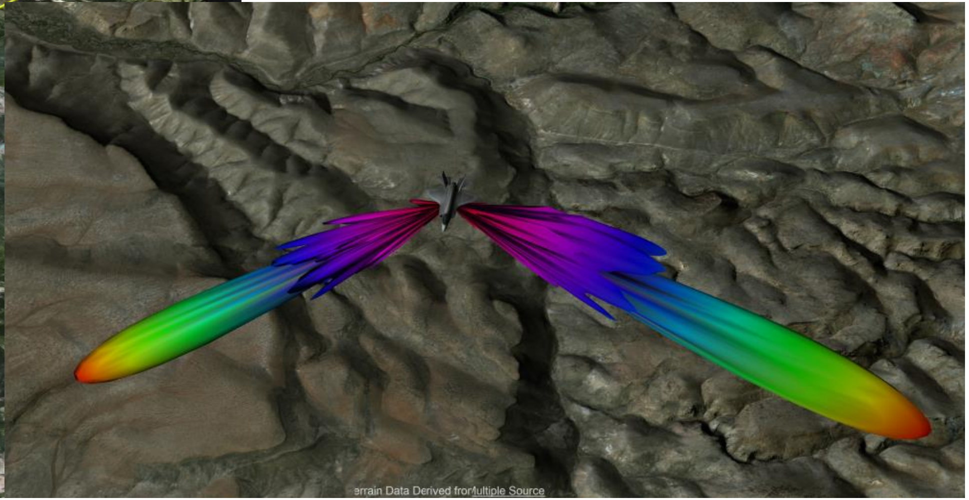


Antenna Gain



Jamming Mitigation – Controlled Antennas





Also, some receiver’s have processing that can detect out-of-family signals, excluding them

Inertial Measurment Units (IMUs)

- Inertial aiding can help when GPS is temporarily lost
  - Without updates, errors will grow
  - Signals of opportunity can help bound errors
- Both a jamming mitigation and alternative nav technique

Alternative Navigation Technologies

- Precise location is an absolute need
- GNSS is not universally reliable
- Other location technologies are available

E-LORAN

- Enhanced Long-Range Navigation
  - Hyperbolic positioning
- 2D positioning, ~8 m accuracy
- Contains auxiliary data, including DGPS corrections

Pseudolites

- Pseudo-satellites
  - Navigation beacons that act as GPS satellites
- Placed optimally, they can minimize **H** matrix for designated flight routes
- Solutions exist for indoor nav as well

Computer Vision and SLAM

- CV techniques use predefined locations combined with sensors on the UAS
- SLAM uses LIDAR to map the area around the UAS, to update its position
  - SLAM = Simultaneous Location And Mapping
  - LIDAR = Light Detection And Ranging

The need for alternatives to GNSS

- We cannot rely on GPS/GNSS navigation alone
- Along with communications and weather prediction, precise location is a critical enabling technology for the UAS industry
- Combinations of navigation technologies are required to support the need for continuous, precise location information

Summary

- The **G** and **H** matrices help us understand navigation errors
- Knowing height references are crucial for safe operations
- Jamming is a prevalent concern
- Several mitigation techniques were reviewed
- Many alternatives to GNSS exist
- A combined system of navigation technologies is needed to provide continual, precise location

Thank you!

@TedDriver

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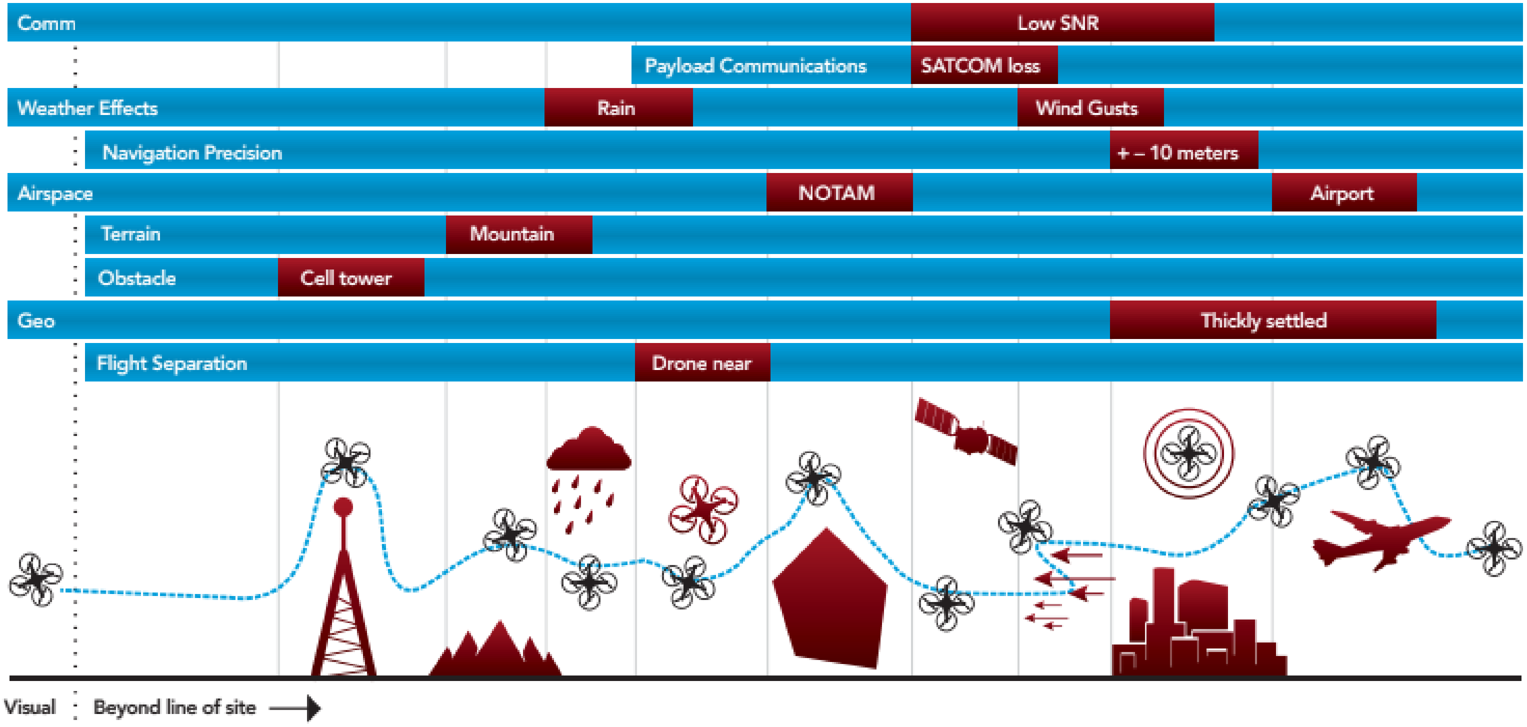

GPS Issues: Contact

- https://www.gps.gov/support/user/
- Suspect jamming?
  - https://www.gps.gov/spectrum/jamming/
  - 1-855-55-NOJAM
  - Also report to the USCG Navigation Center


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