PNT Research in the System-Wide Safety (SWS) Project

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Areas of work: (1) APNT Studies; (2) NavQ service concept;
(3) multipath mitigation

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Alternative Positioning, Navigation and Timing (APNT) Testing

National Defense Authorization Act for Fiscal Year 2018 (H.R. 2810), Section 1606:

- "Demonstration of Backup and Complementary Positioning, Navigation and Timing (PNT) Capabilities of the Global Positioning System (GPS)"

2018 DHS-led APNT Testing:

APNT System	Test Location	Tech Category
NextNav	NASA LaRC	Local RF
Locata	NASA LaRC	Local RF
[redacted]	NASA LaRC	[redacted]

NextNav Equipment Installed at NASA LaRC

2019-2020 DoT-led APNT Testing:

APNT System	Tech Category
TRX	Map Match
NextNav	Local RF
Skyhook	Local RF
Echo Ridge	Satellite
OPNT	Fiber Optic
Seven Solutions	Fiber Optic
Satelles	Satellite
Hellen Systems	Terrestrial RF
UrsaNav	Terrestrial RF
Serco	Terrestrial RF
PhasorLab	Terrestrial RF

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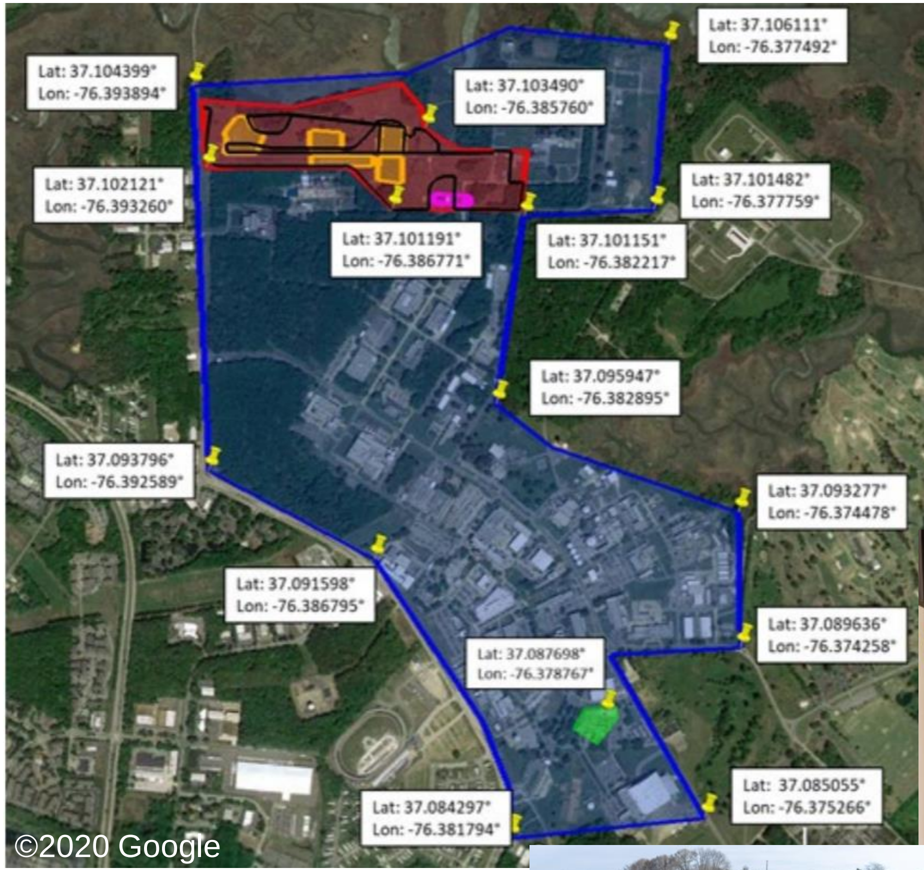
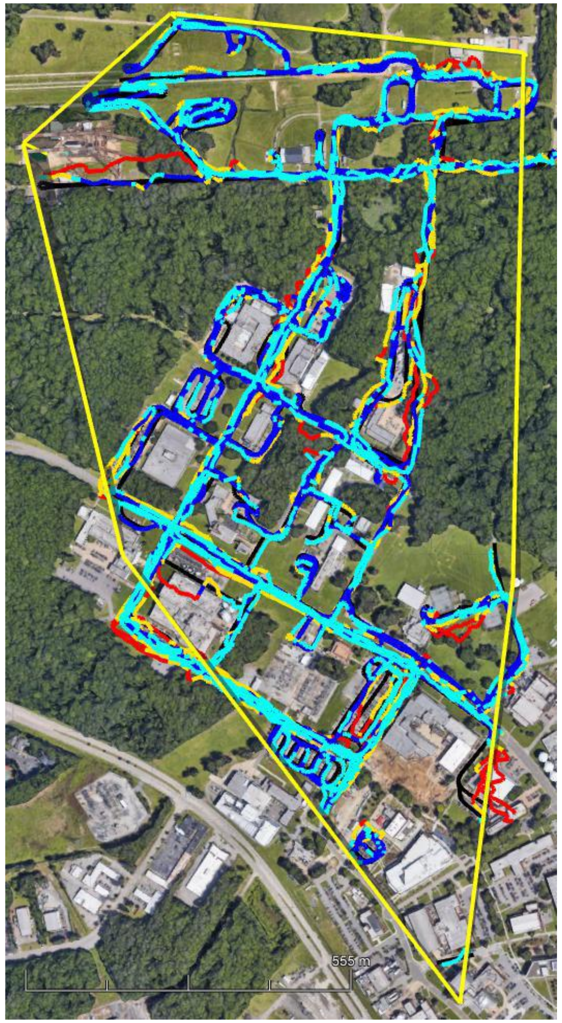
APNT Testing





Report:

https://www.transportation.gov/sites/dot.gov/files/2021-01/FY%2718%20NDAA%20Section%201606%20DOT%20Report%20to%20Congress_Combinedv2_January%202021.pdf

Current State, Gaps and Challenges

There is no single APNT system that can serve as a universal backup for GPS.

"…*there are suitable, mature and commercially available technologies to backup or complement the timing services provided by GPS. However, the demonstration also indicates that none of the systems can universally backup the positioning and navigation capabilities provided by GPS and its augmentations*." [1]

No silver bullet! – currently must design for a specific CONOPS:

Future work:

- Establishing requirements and performing gap analysis for specific CONOPS
  - More generalized proposals being investigated by standards bodies (e.g., ASTM, RTCA, etc.)
- Reliable performance at low altitudes and in complex environments
  - Extreme multi-path
  - Sparse signal availability
  - Cyber-security threats
  - Spoofing
- Tailored and dependable integrated solutions with reasonable SWAP-C
  - Combine multiple PNT sources (e.g. GPS/INS/APNT/GBAS/Optical/etc.)
  - Integration strategies (EKF, UKF, particle filter, cross-checking, etc.)

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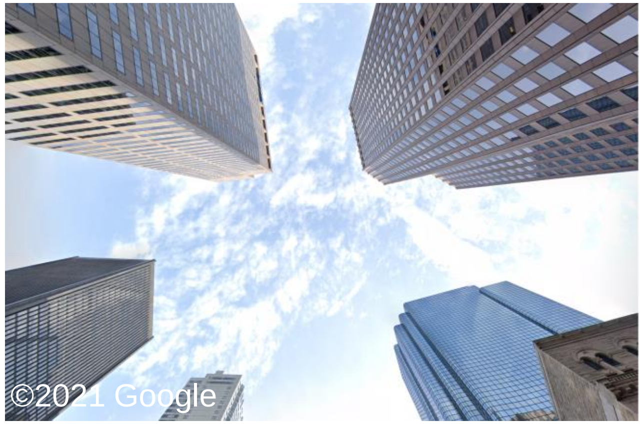
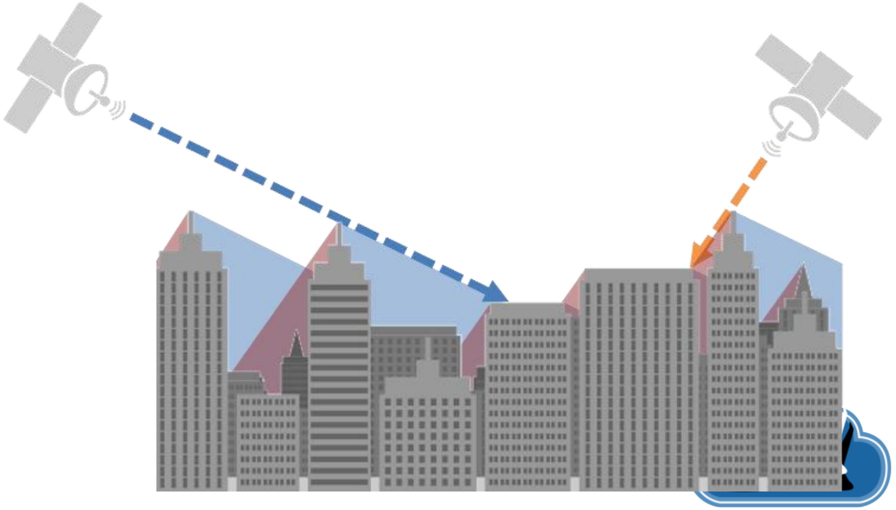
RF Navigation Modeling and Prediction (NavQ)

- **Urban areas are notoriously difficult for GPS**
  - The quality of a GPS position solution is largely correlated to the number of satellites within direct line of sight and the geometry of those satellites.
  - In low altitude, urban flight operations, it is common to have objects (e.g., buildings, terrain, foliage) completely or partially obstruct the direct line to GPS satellites.
  - Multipath effects can also be significant
- **Result**
  - Constraints on use for commercial aviation
  - Some mishaps/accidents for small UAS already

Financial District, Boston, Massachusetts





NavQ

What it is: A prognostic PNT performance service supporting future highly autonomous air vehicle ops

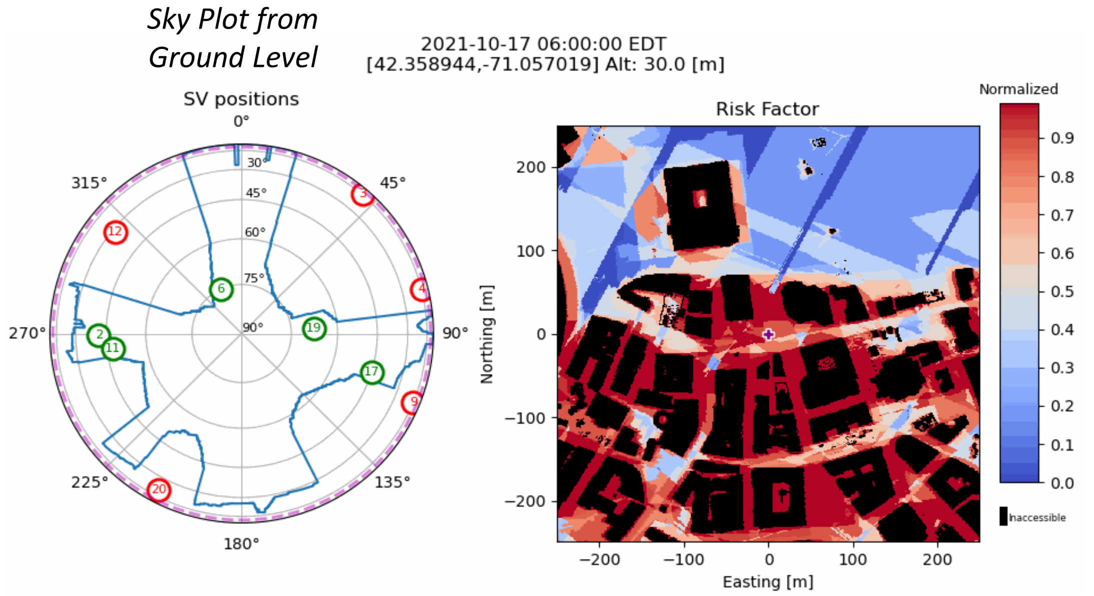
Goal: Mitigate nav-related safety risks such as those posed by degraded GPS performance during novel urban flight operations

Encompasses: (1) model-based predictions; (2) access to augmentation information; and (3) connectivity to Alternative Positioning, Navigation and Timing (APNT) infrastructure

Current version of (1) predicts the quality of GNSS based position estimates for urban flight operations

- Produces a discretized time-varying 4D volume that estimates GPS-related metrics (e.g. HDOP) across a chosen flight environment and time period.
- Can support both flight planning and in-flight uses
- Requires a digital surface model of the flight area
- 2nd tool capable of ingesting foliage data for flights near vegetation

Financial District, Boston, Massachusetts



Partnership with OGA: Assessing operational usability/ utility in multiple urban areas during large scale events:

- Kentucky Derby
- Macy's Thanksgiving Day Parade
- New Year's Eve in Times Square
- Boston Marathon
- NFL Draft

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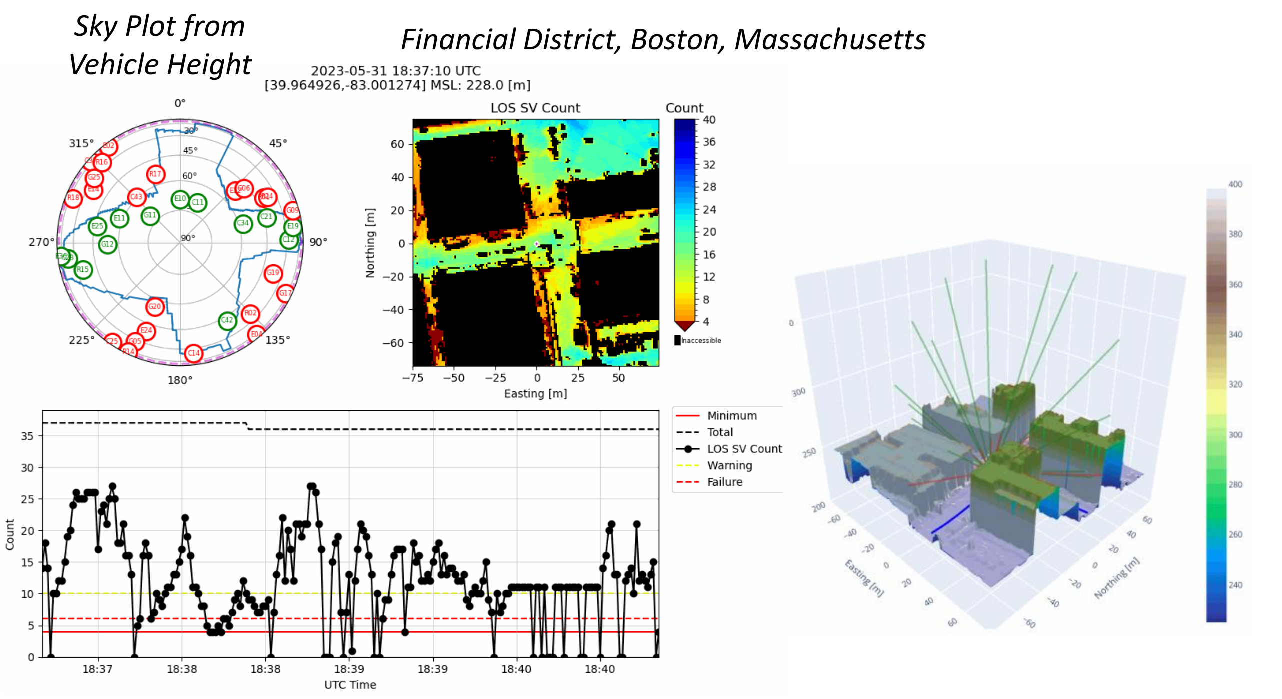

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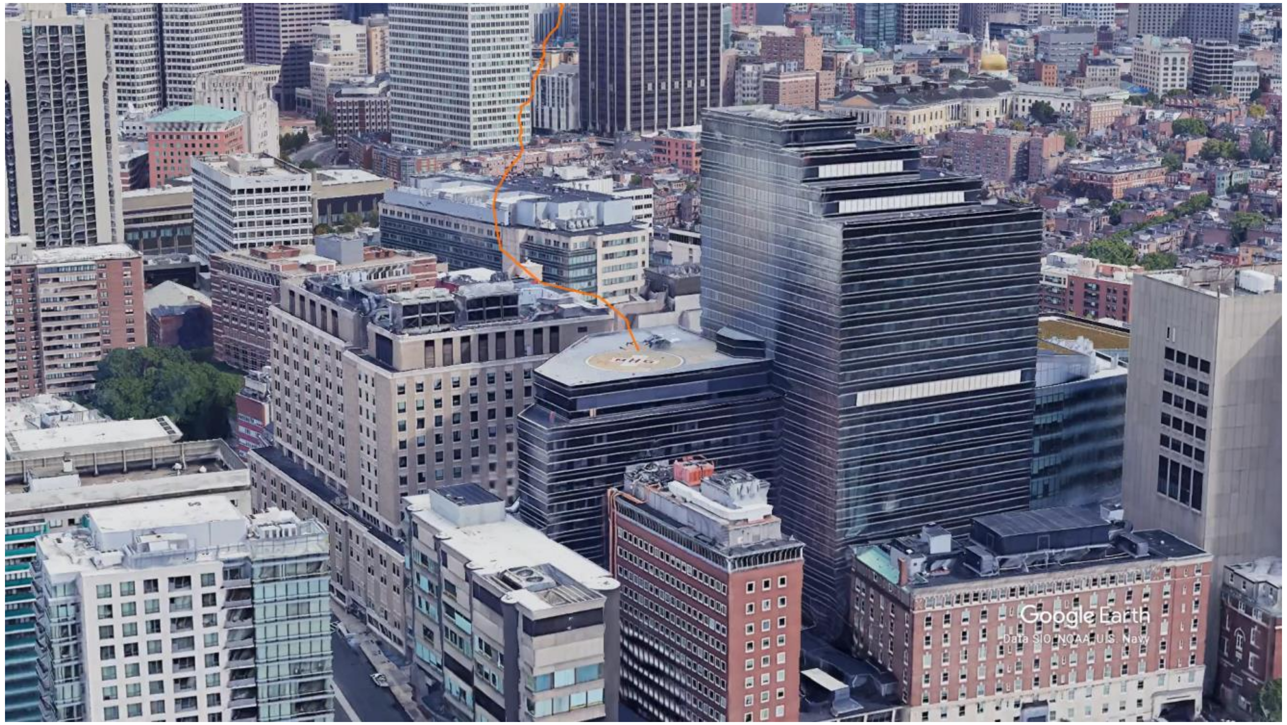
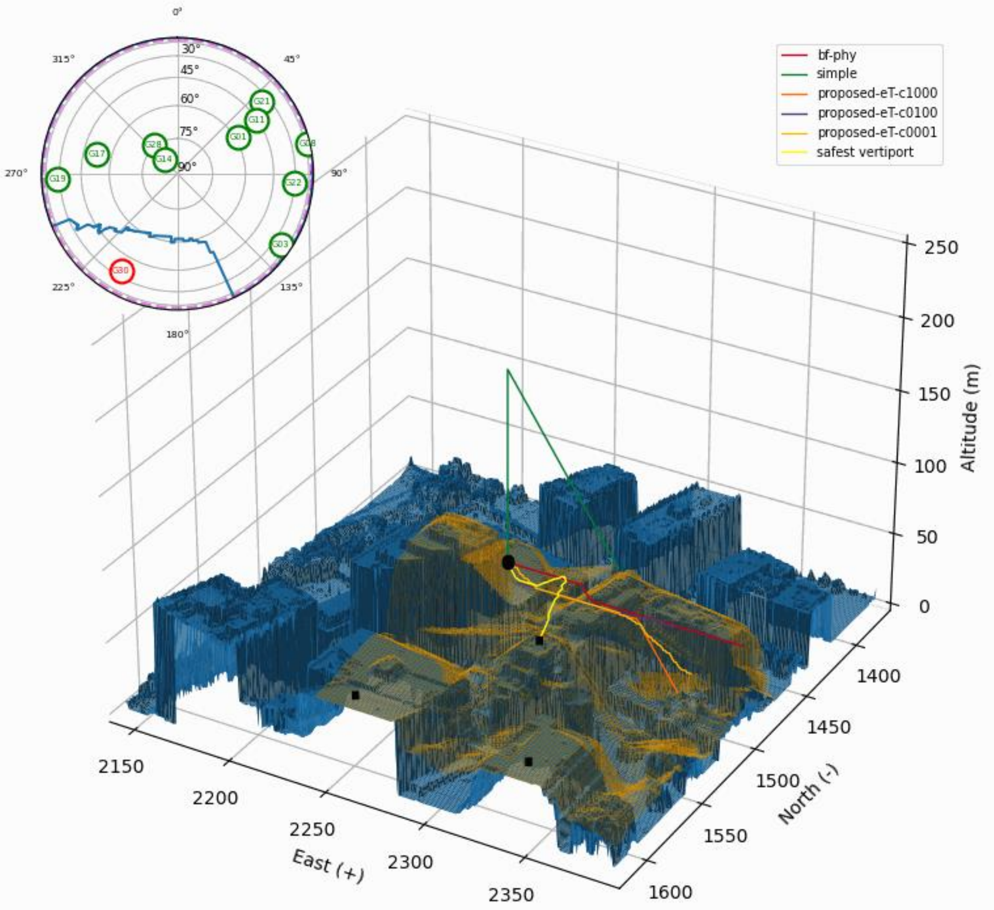
Flight Planning Based on Risk of Degradation of Navigational Data





Experimental Validation of NavQ

- **Data Collection** (collaborative w LSUASC)
  - ➢ Real-time geolocation measurements:
    - – 3 days in 2022: June 6, July 28, August 27
    - – Different start time, ~5 miles across ~1 hour, each day
    - – Through unobstructed areas as well as dense urban canyons of Corpus Christi, TX
- **Sensors**
  - ➢ u-Blox Zed-F9P receiver configured to receive L1 and L2 band signals from GPS and Glonass
  - ➢ Ruggedized VN-200 antenna configured to receive L1 signals from GPS constellation and produce a tightly integrated GPS/IMU solution
  - ➢ CORS station TXPO (for kinematic RTK)

Ground truth (green) and computed position from receiver data (cyan) on June 6, 2022

Measurement rig

@Map data: Google, SIO, US Navy, NGA, GEBCO, Landsat/Copernicus

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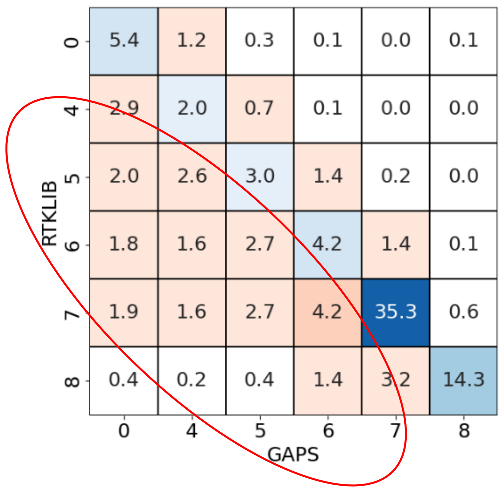
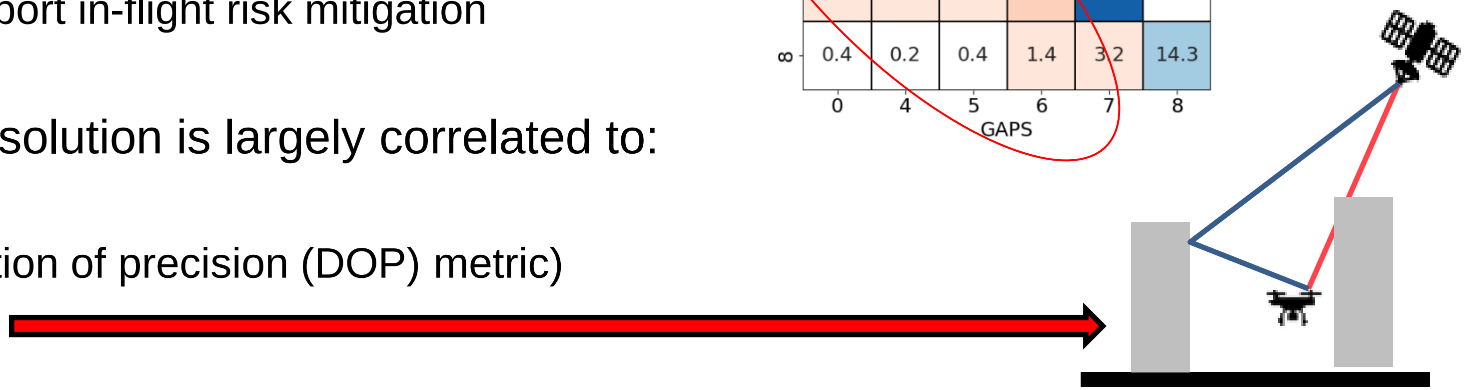
Experimental Validation of NavQ - Conclusions

➢ Navigation fidelity prediction services were experimentally validated:
1. Comparison with over 6000 GNSS readings
2. Diverse environment
3. Multiple days/times = different constellation configuration
4. NavQ SFCs can aid in planning and support in-flight risk mitigation



➢ Overall quality of a GPS based position solution is largely correlated to:
1. The number of SVs observed
2. The geometry of the available SVs (dilution of precision (DOP) metric)
3. The correctness of the available signals



Comparing SV count and SV IDs between predicted and observed was used for validation.

- **Incidence of false positive predictions were much lower than that of false positive. Why???**

Ongoing Work: Multipath!

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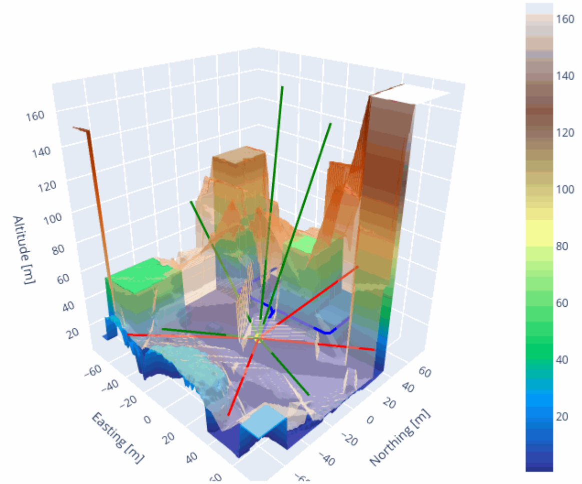
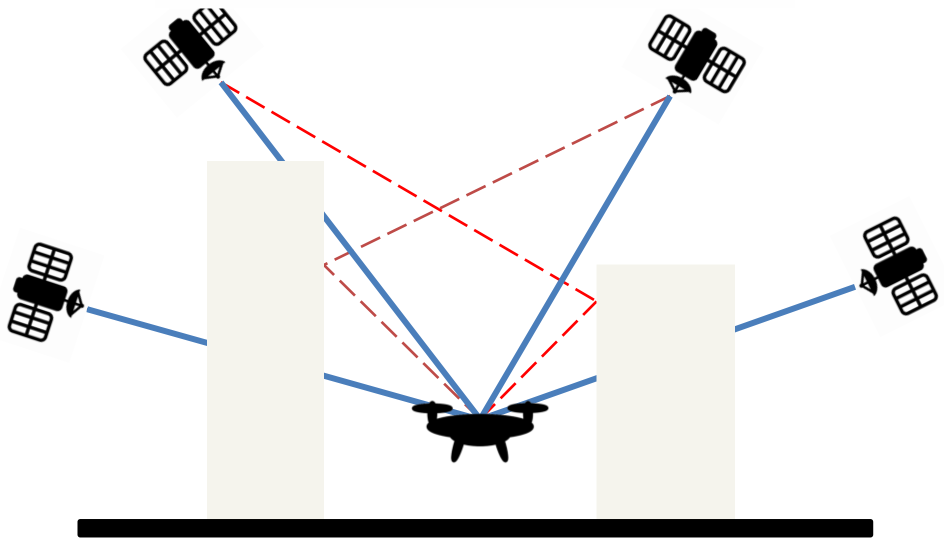
The Multipath Problem for GNSS

GNSS receivers will generally use all SV's available to them when calculating a solution

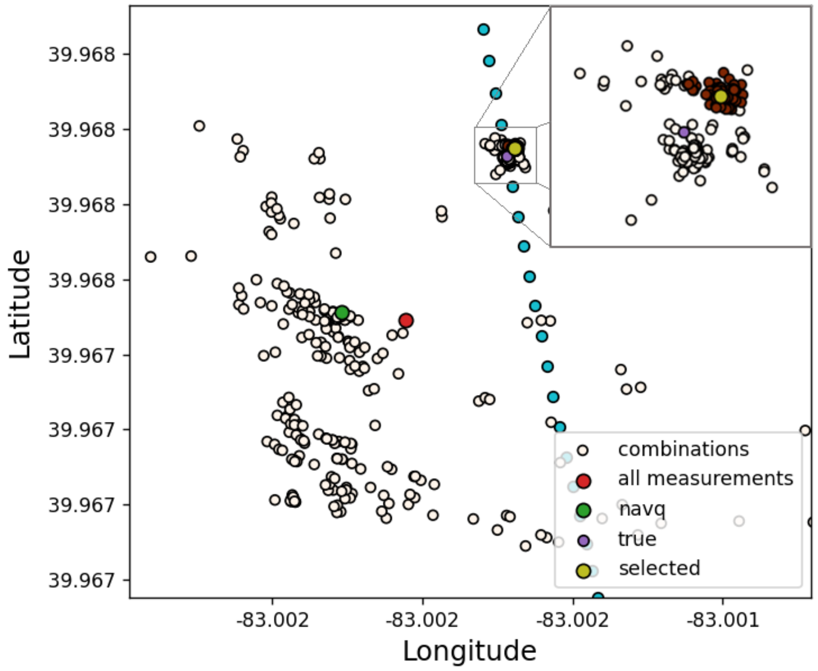
- Great when operating in an open sky area
- Can be challenging in urban environments due to:
  - Reduced number of visible satellites
  - Line-of-sight (LOS) multipath
  - Non-line-of-sight (NLOS) multipath
- Receivers may not know if a satellite is NLOS and might use it (mitigation option: NavQ)
- Even if we know the satellite is LOS, the signal might be affected by multipath

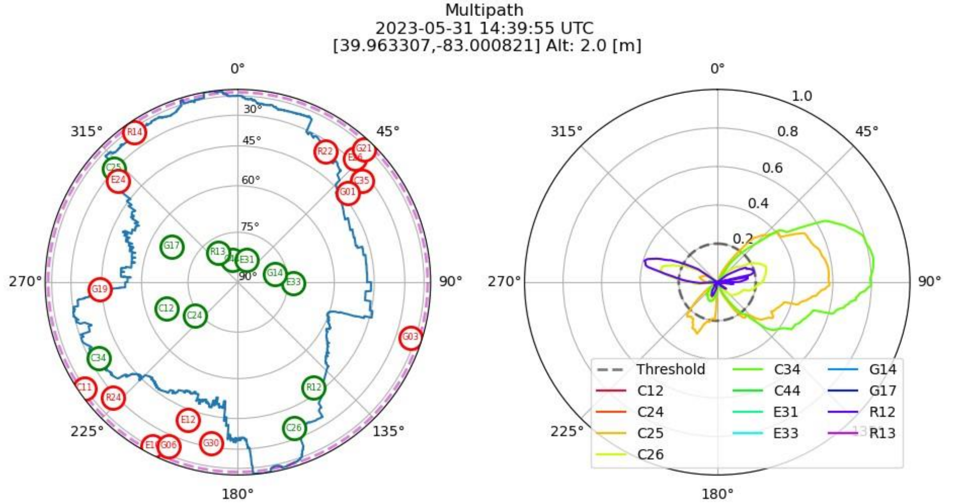




Multipath Mitigation – Clustering Approach

- We have developed a technology that figures out which satellites are causing positioning errors and removes them from the final solution
- To do so, we use:
  1. NavQ to remove NLOS satellites
  2. A simplified multipath model add-on to NavQ that determines which LOS SVs could be affected by multipath
  3. An HPC-driven clustering approach to identify which SVs from the multipath model contain significant LOS multipath

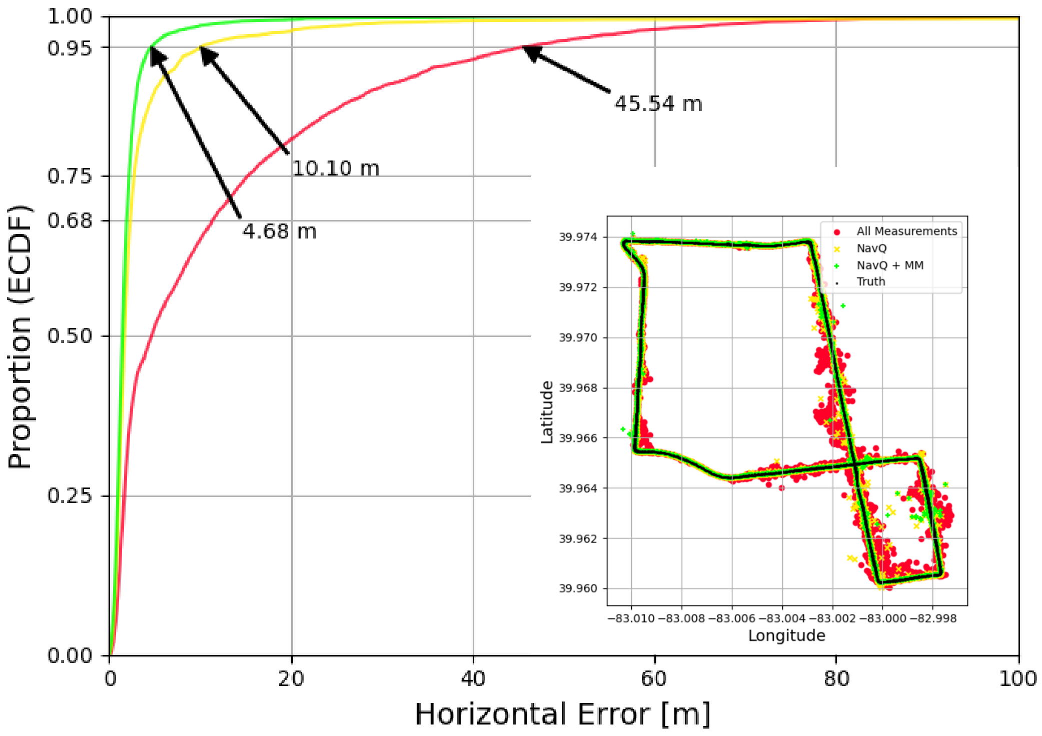


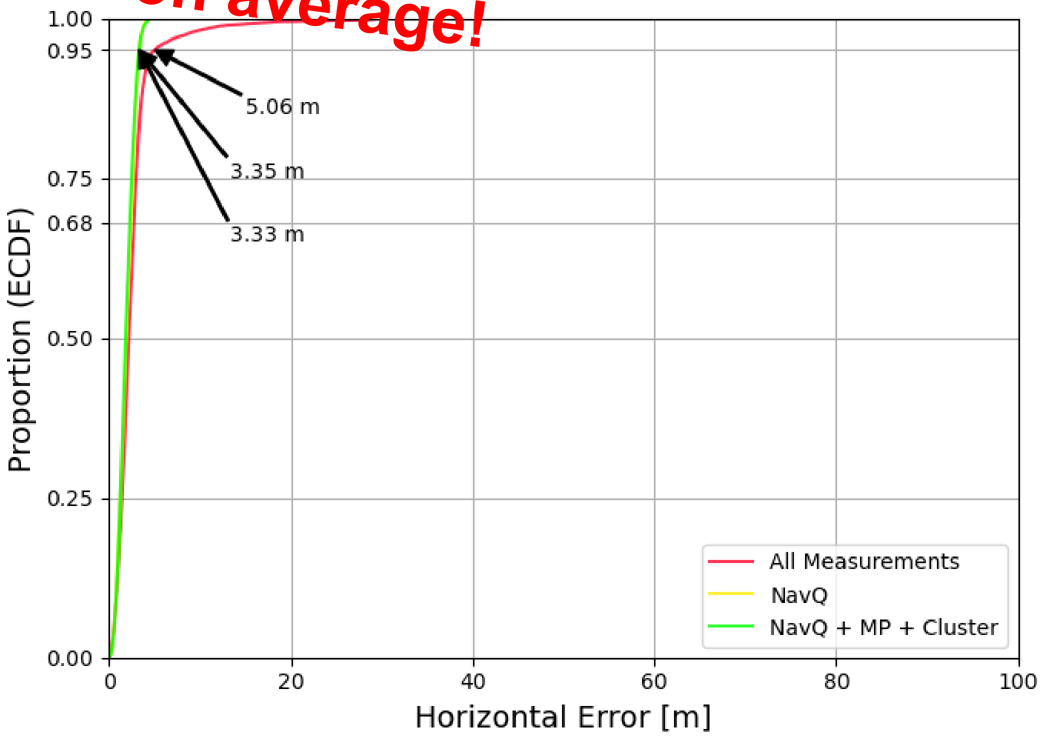


Multipath Mitigation – Clustering Approach

And we can reach these solutions in 1.2 s on average!

- Current results are promising:





- **5475 measurements in mixed urban scenario**
- **11520 measurements in static moderately open sky scenario**

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Thank you!

Questions?

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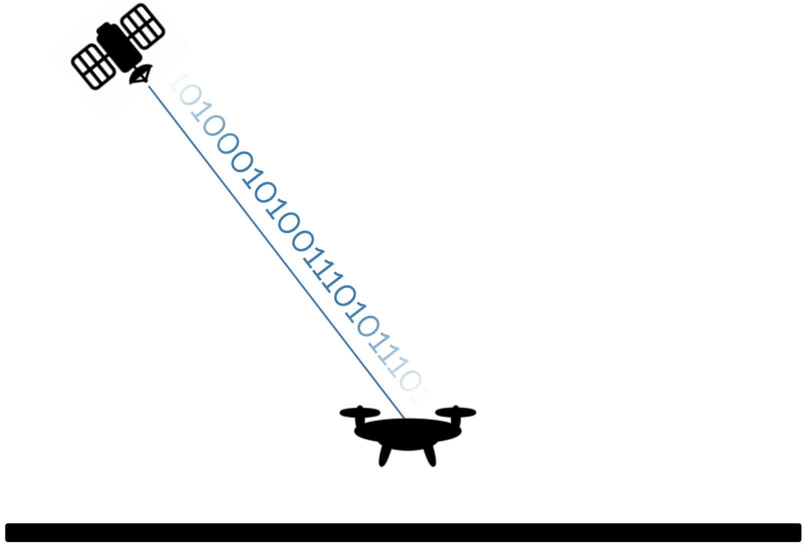
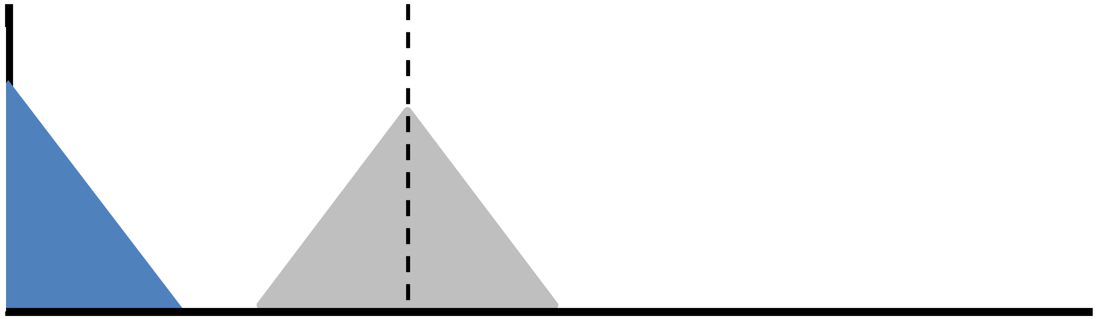
The Multipath Problem for GNSS

- Each satellite broadcasts a stream of known pseudorandom numbers (PRN)
- Receivers compare this to a local stream to determine the range measurement
- Under ideal circumstances, this gives a sufficient range estimate



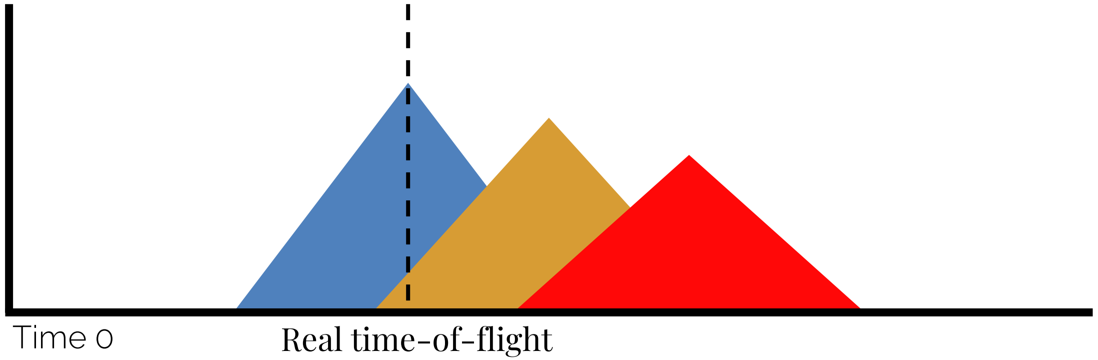
Broadcast PRN	1011010111010001010011101011101011100010100001
Receiver PRN	1011010111010001010011101011101011100010100001

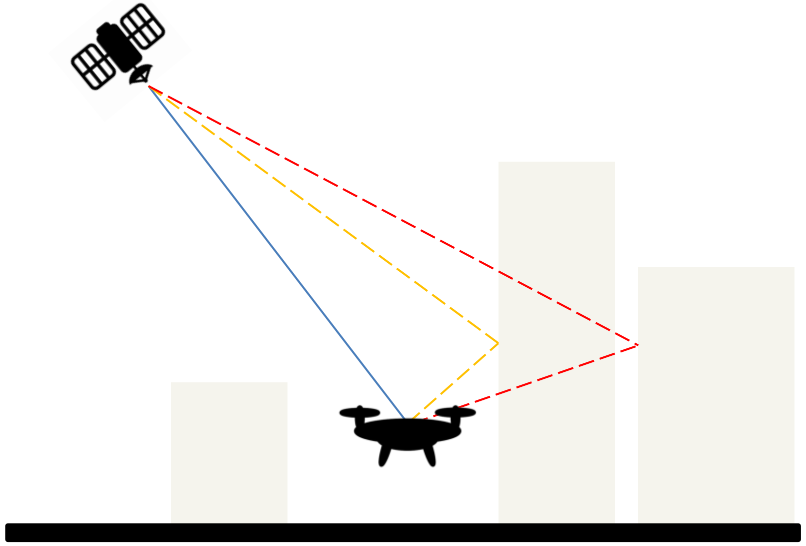


The Multipath Problem for GNSS

- Multipath can skew this measurement

Broadcast PRN	101101011101000101001110101110101110001010001
Bounce 1	101101011101000101001110101110101110001010001
Bounce 2	101101011101000101001110101110101110001010001





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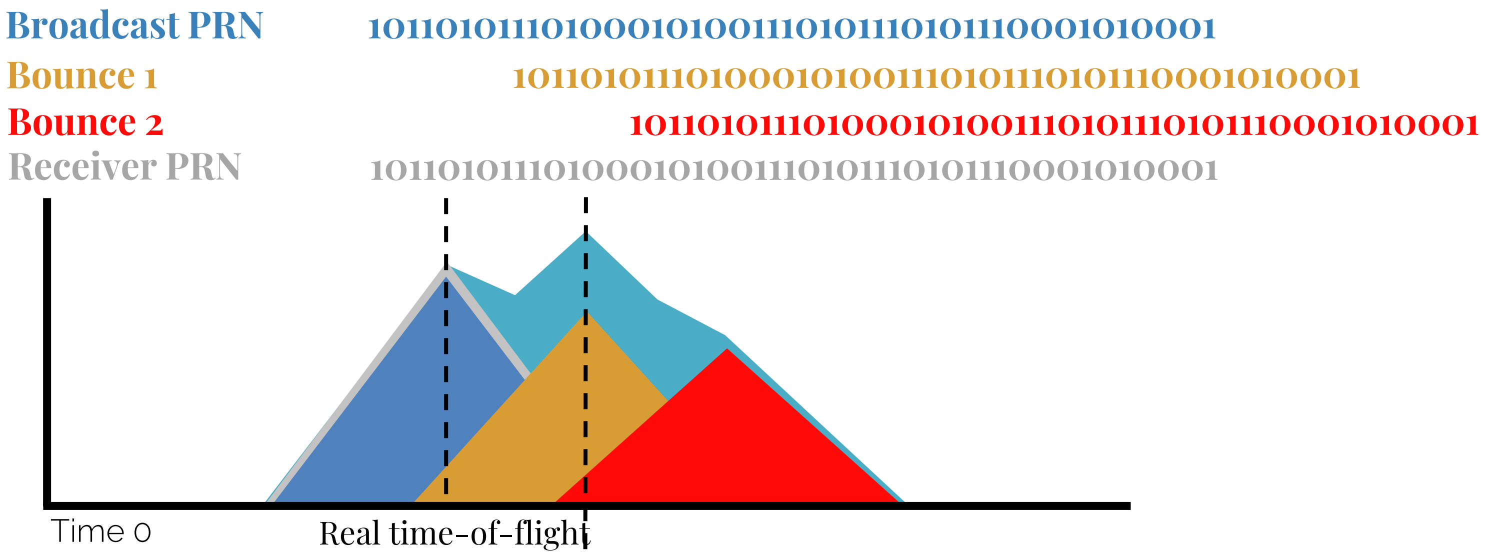
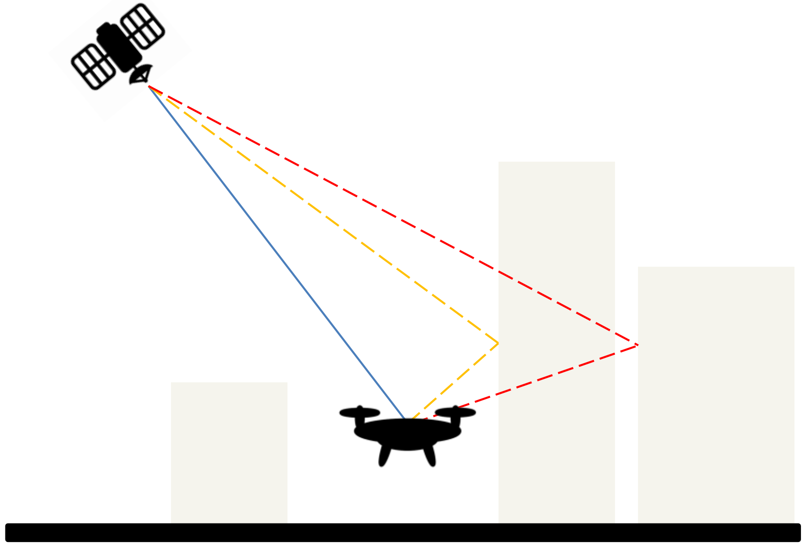
The Multipath Problem for GNSS

- Multipath can skew this measurement
- The receiver correlates on the composite of the measurements it receives
- Varies greatly depending on conditions





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