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Sharing and Crowdsourcing GNSS Data to Monitor and Protect the GNSS RF Environment

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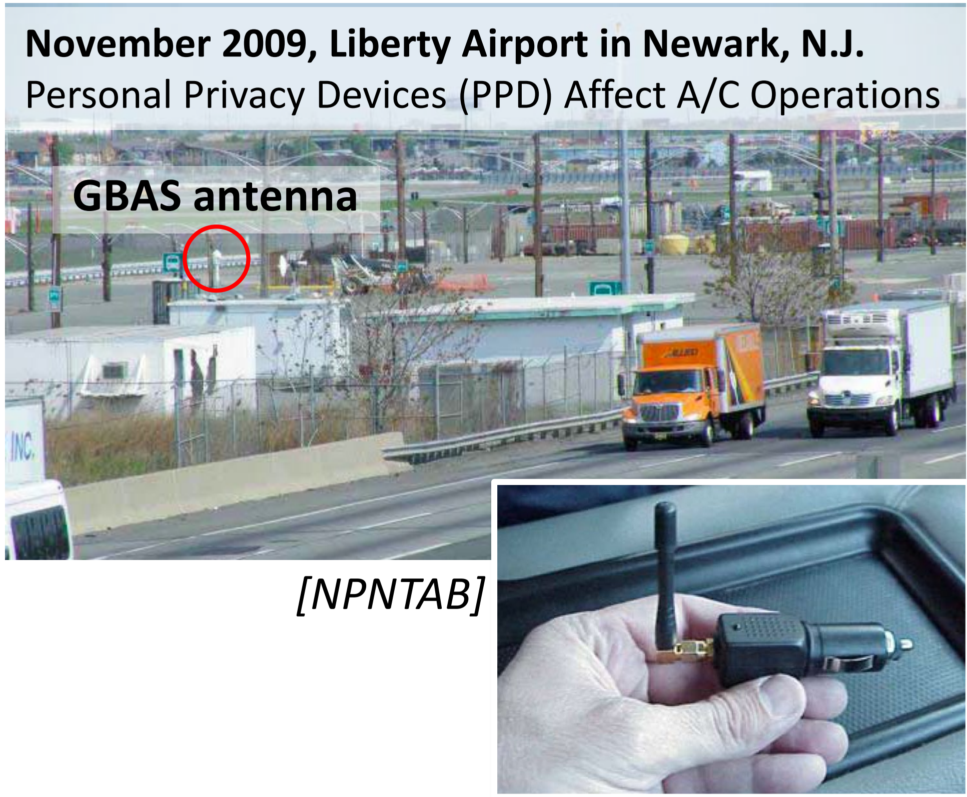
December 2022 - 10th ICG Workshop on GNSS Spectrum Protection and Interference Detection and Mitigation

Background

- GNSS Radio-Frequency Interference (RFI), including **jamming and spoofing**, are a growing threat to GNSS *[NSBPNTAB, Brunker]*
  - Local-area jamming, e.g.,
    from Personal Privacy Devices (PPDs)
  - Wide-area jamming, e.g., in conflict areas,
    or due to unintentional jamming
    - ➢ with **growing reliance on GNSS** for tracking and automation comes **new motives** for disturbance and manipulation


November 2009, Liberty Airport in Newark, N.J.

Personal Privacy Devices (PPD) Affect A/C Operations

[NPNTAB]

- Yet, **we are lacking a coordinated, deliberate, public response** to achieve Positioning Navigation and Timing (PNT) situational awareness
  - we need a “weather channel” for the RF environment (this does not need to be limited to GNSS RFI)

[NSBPNTAB] National Space-Based PNT Advisory Board. “Protect, Toughen, and Augment Global Positioning System for Users.” gps.gov, 2018.

[Brunker] M. Brunker, “GPS under attack as crooks, rogue workers wage electronic war,” News Brief at NBC, 2016.

[NPNTAB] National PNT Advisory Board, “Comments on Jamming the Global Positioning System - A National Security Threat: Recent Events and Potential Cures,” 2010

Motivation and Focus

- RFI monitoring using publicly available data has been demonstrated, **but typically provides circumstantial evidence of jamming/spoofing using opportunistic data** *[C4ADS, GBS Scott, Miralles, Strizic]*
  - using crowd-sourced data, shared by **volunteers**
  - using data of opportunity: **not dedicated** to RFI monitoring (often missing), posted with significant **latency**
    - *Were the detected events **actual RFIs?** Are they **impacting GNSS now?***
    - *What if we made **a more deliberate effort** to address RFI?*

- In this presentation:
  - Example: **GNSS jamming monitoring** using data of opportunity from traffic management systems
  - Our effort: opportunistic data to **find suspected jammers**, dedicated equipment to **prove jamming**

[C4ADS] C4ADS. “Above us only stars.” Tech. Rep., 2019.

[GBS] Bjorn Bergman. “Systematic Data Analysis Reveals False Vessel Tracks.” Data and technology, News & Views, Research and analysis, 2021

[Scott] L. Scott, “J911: The case for fast jammer detection and location using crowdsourcing approaches,” ION GNSS 2011

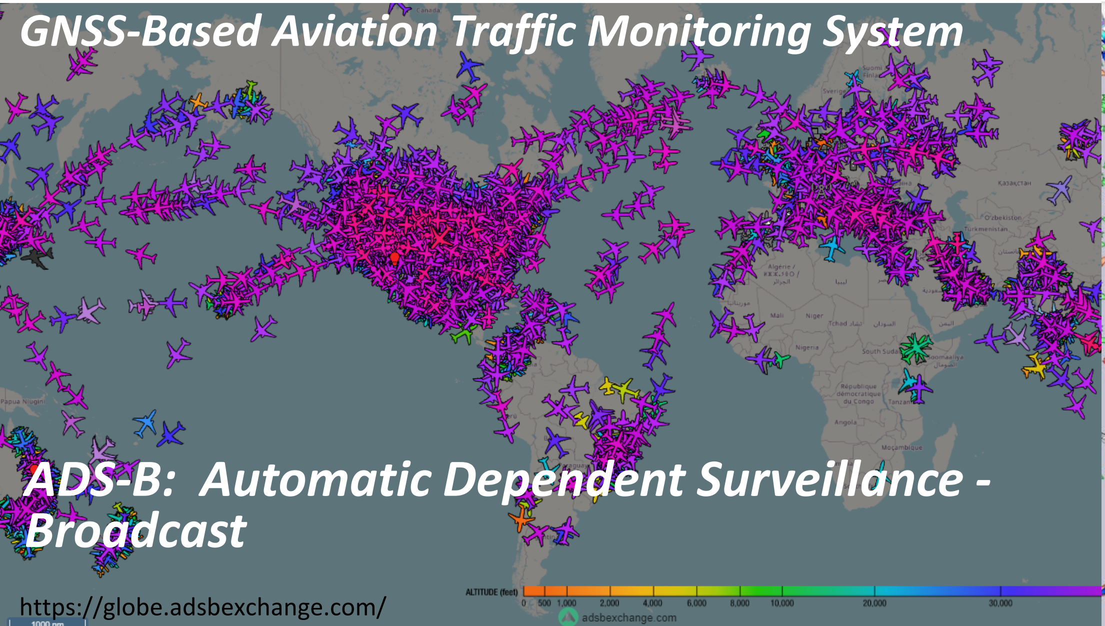
[Miralles] D. Miralles, N. Levigne, D. M. Akos, J. Blanch, and S. Lo, “Android raw GNSS measurements as the new anti-spoofing and anti-jamming solution,” ION GNSS+ 2018.

[Strizic] L. Strizic, D. M. Akos, and S. Lo, “Crowdsourcing GNSS jammer detection and localization,” ION ITM 2018.

GNSS Jamming and Spoofing

- Threats to GNSS and a major concern in aviation:
  - **Spoofing**: faking GPS (for misleading, high-jacking)
  - **Jamming**: denial of service

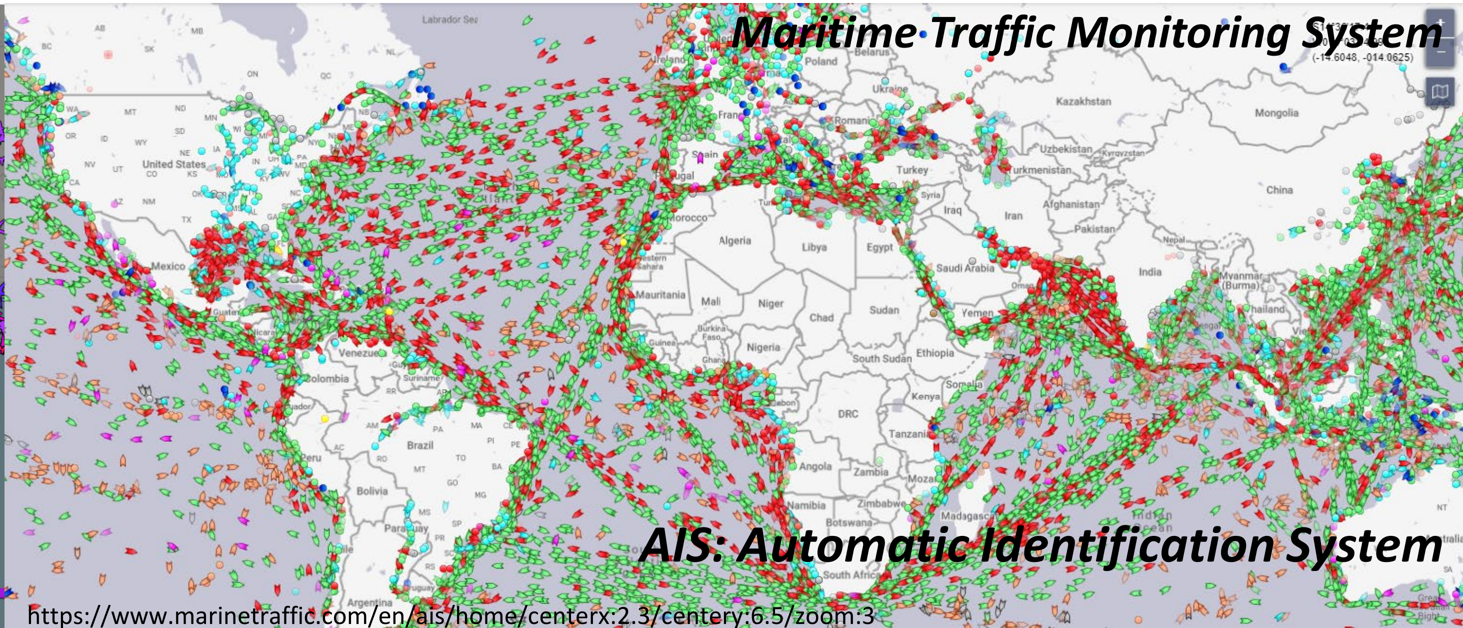
- **Large, wide-spread GNSS jamming** can be observed using publicly available data



GNSS-Based Aviation Traffic Monitoring System

ADS-B: Automatic Dependent Surveillance - Broadcast

https://globe.adsbexchange.com/



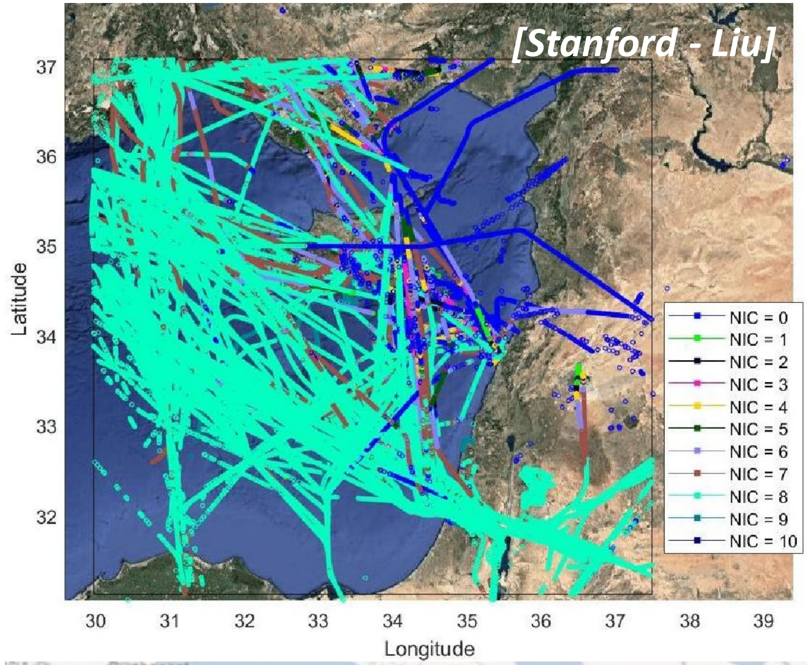
Maritime Traffic Monitoring System

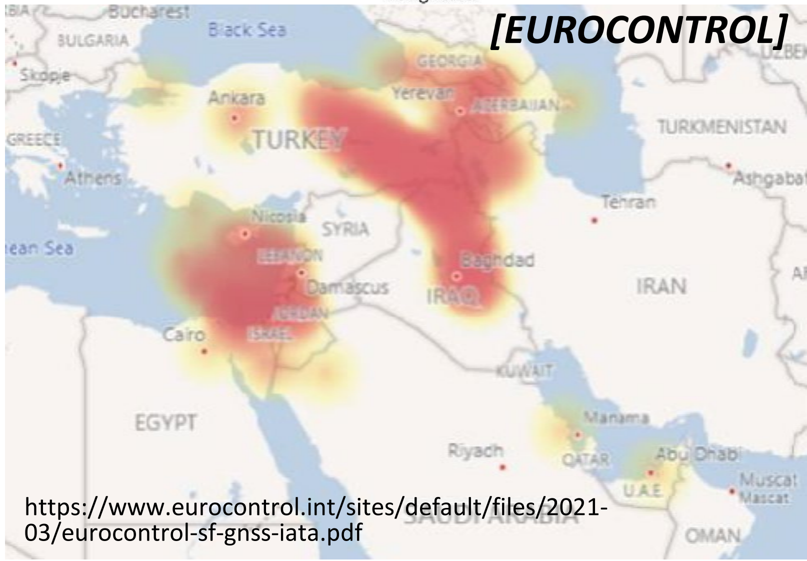
AIS: Automatic Identification System

https://www.marinetraffic.com/en/ais/home/centerx:2.3/centery:6.5/zoom:3

Using ADS-B to Localize Jamming in Syria (September 2020)

- ADS-B is a GNSS-based traffic monitoring system
  - aircraft are required to share their location
  - ADS-B In receivers (e.g., VT) access air traffic data and can voluntarily share it online (e.g., adsbexchange.com)
- Liu et al. analyzed ADS-B data during jamming incidents in Cypriot and Syrian airspace in September 2020. *[Liu]*
  - ADS-B data include **NIC: Navigation Integrity Category** – indicator of containment radius
- A heat map of RFI pilot reports in the region was also generated *[EUROCONTROL].*


[Stanford - Liu]

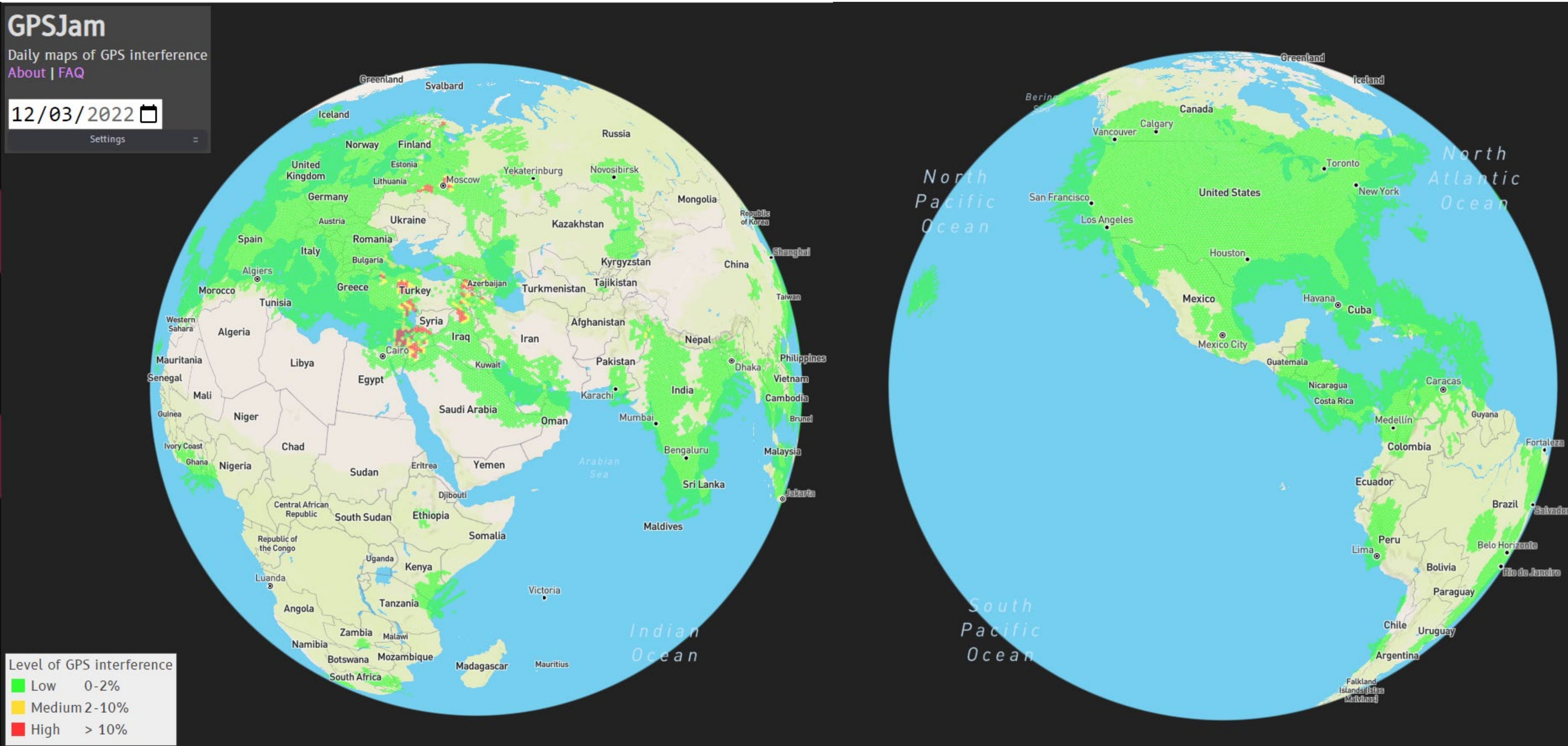

[EUROCONTROL]

https://www.eurocontrol.int/sites/default/files/2021-03/eurocontrol-sf-gnss-iata.pdf

[Stanford – Liu] Liu, Z., Lo S., & Walter, T. “GNSS Interference Detection Using Machine Learning Algorithms on ADS-B Data.” *ION GNSS+ 2021.*

[EUROCONTROL] N. Pringvanich, “GNSS Interference: Impacts to airline operations.” 2021.

ADS-B-based Online Daily RFI Monitor



GPSJam

Daily maps of GPS interference

About | FAQ

12/03/2022

Settings

Level of GPS interference

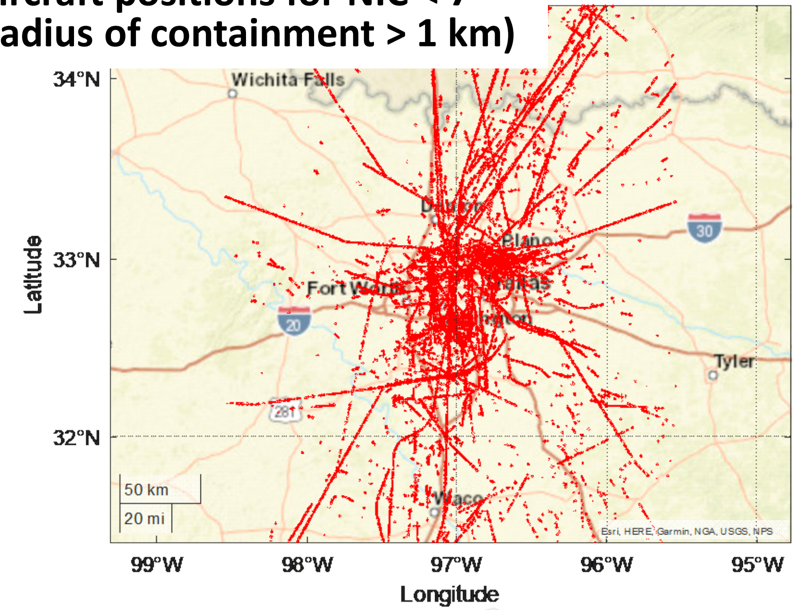
🟩 Low 0-2%

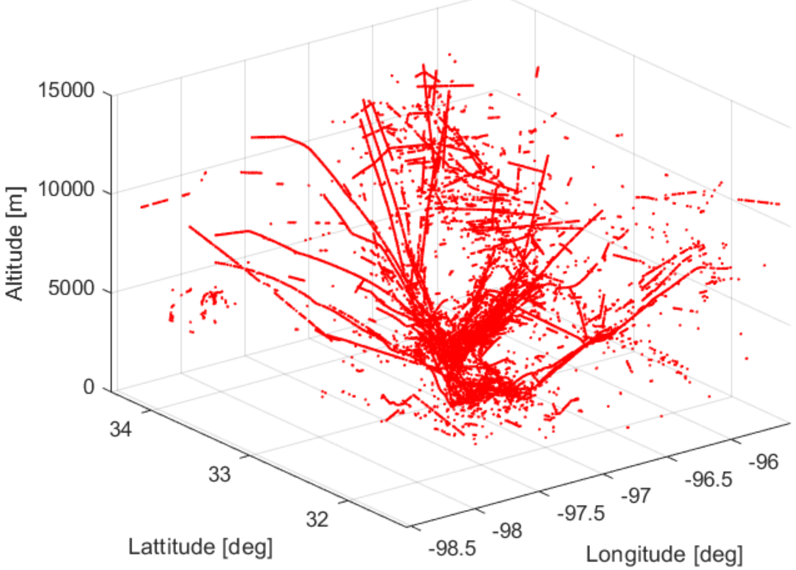
🟨 Medium 2-10%

🟥 High > 10%

Dallas Fort Worth (DFW) Airport (October 17-18 2022)

Aircraft positions for NIC < 7
(radius of containment > 1 km)

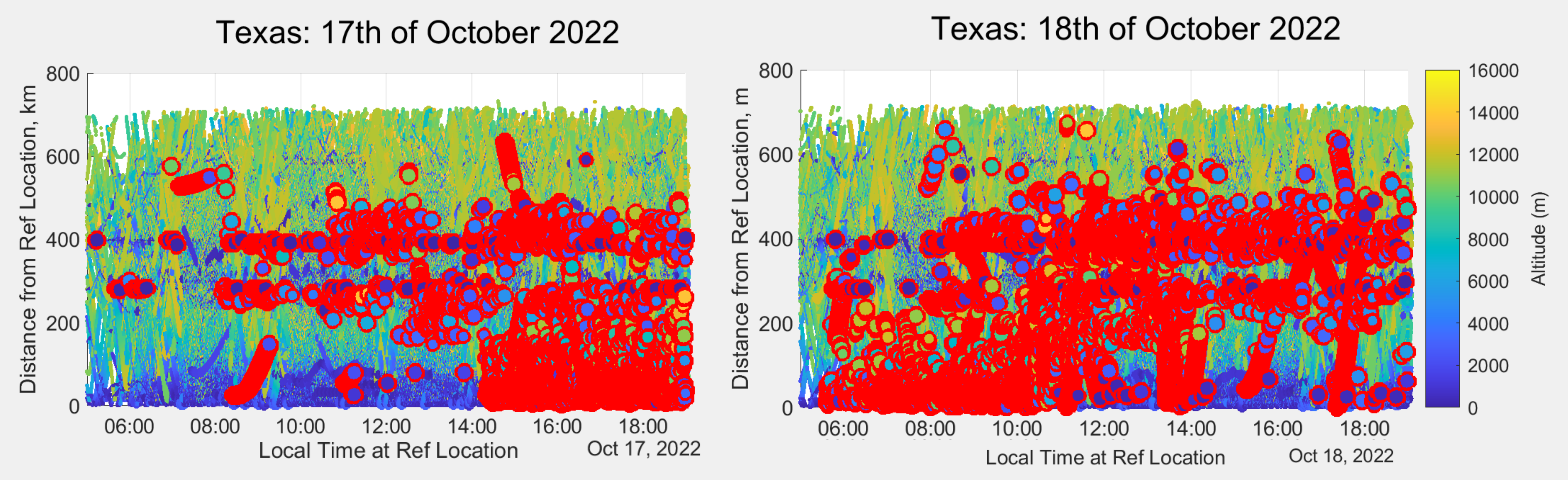




(UTC)

Dallas Fort Worth (DFW) Airport (October 17-18 2022)

- Widescale disturbance in the US National Airspace System – *cause unknown*
  - This event: obvious strong, wide-scale disturbance – **proof** by number of impacted users
  - In general: **how to identify actual jamming ?**
    and distinguish it from a large containment radius dur to poor GNSS?

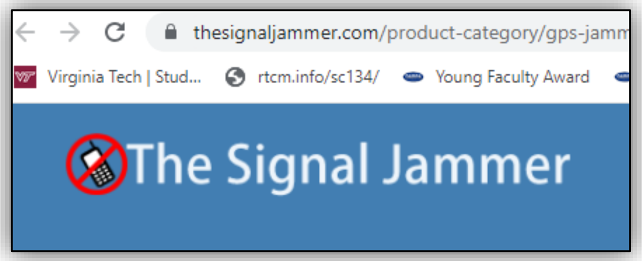


Texas: 17th of October 2022

Texas: 18th of October 2022

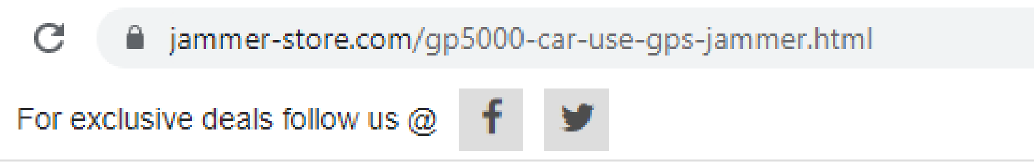
Focus on Widespread Jamming Issue

- **Motivation**:
  - avoid tracking by employers, authorities, (fishing, trafficking, toxic waste disposal), tracking by a significant other…
- **Jamming devices:**



thesignaljammer.com/product-category/gps-jamm

The Signal Jammer



jammer-store.com/gp5000-car-use-gps-jammer.html

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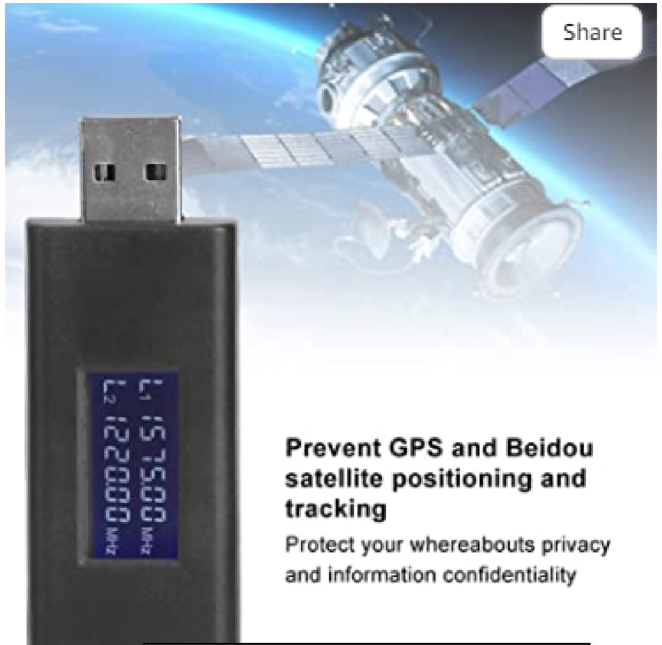
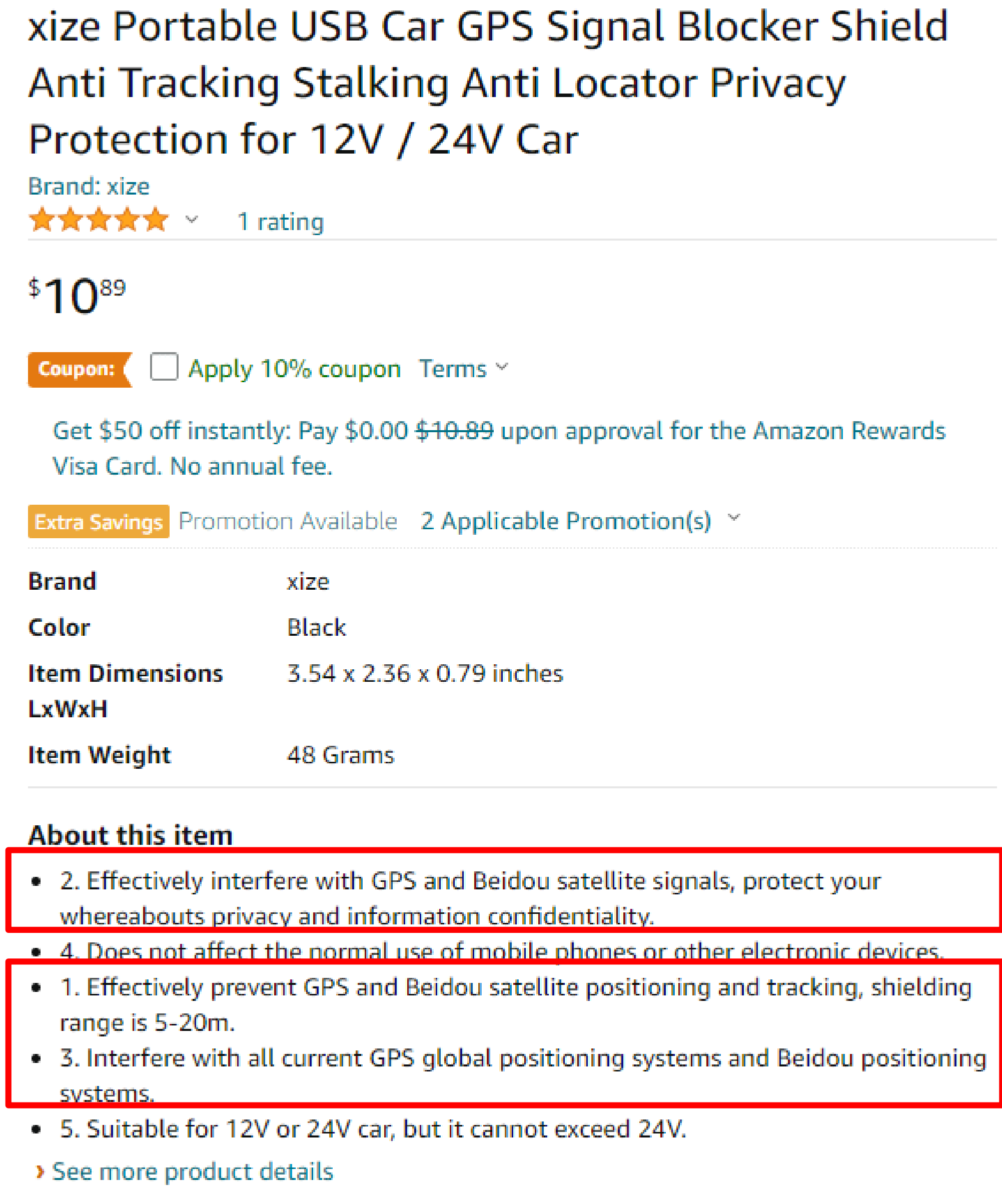
Privacy Protection



Prevent GPS and Beidou satellite positioning and tracking

Protect your whereabouts privacy and information confidentiality

> *"Your work is important, thanks for helping protect people from the tyranical exploitation of advanced technology"*
>
> TechCrunch.com



xize Portable USB Car GPS Signal Blocker Shield Anti Tracking Stalking Anti Locator Privacy Protection for 12V / 24V Car

Brand: xize

★★★★★ 1 rating

$10.89

Coupon: □ Apply 10% coupon Terms

Get $50 off instantly: Pay $0.00 ~~$10.89~~ upon approval for the Amazon Rewards Visa Card. No annual fee.

Extra Savings Promotion Available 2 Applicable Promotion(s)

Brand	xize
Color	Black
Item Dimensions LxWxH	3.54 x 2.36 x 0.79 inches
Item Weight	48 Grams

About this item

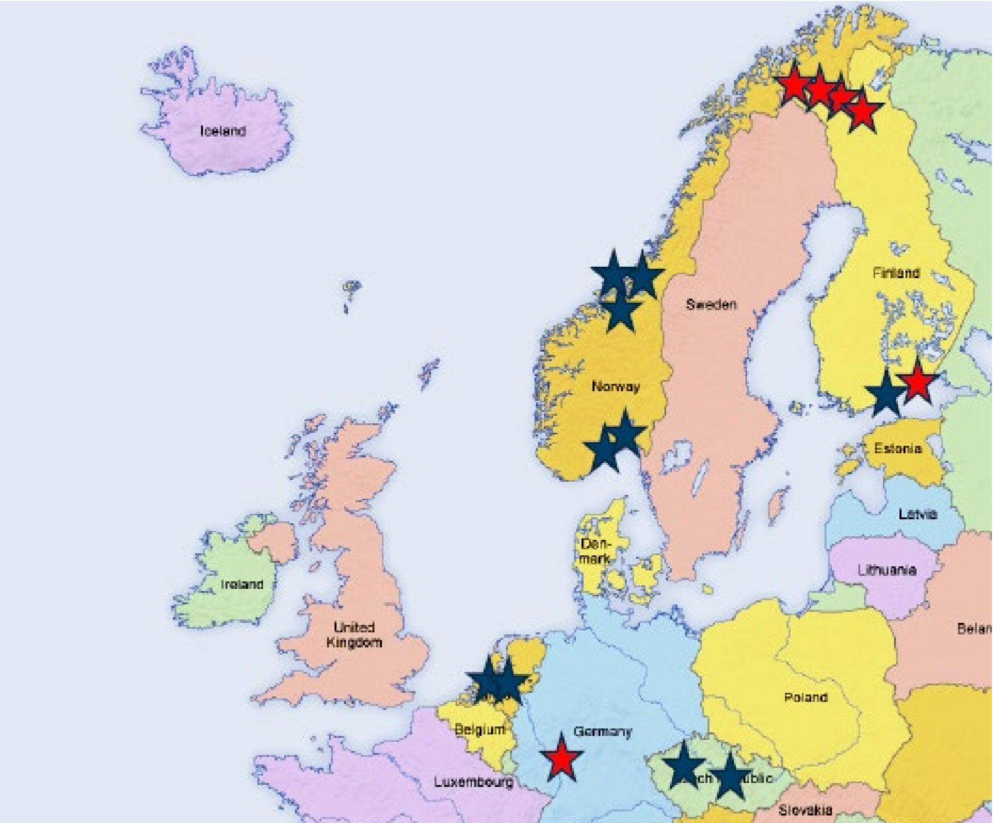
- 2. Effectively interfere with GPS and Beidou satellite signals, protect your whereabouts privacy and information confidentiality.
- 4. Does not affect the normal use of mobile phones or other electronic devices.
- 1. Effectively prevent GPS and Beidou satellite positioning and tracking, shielding range is 5-20m.
- 3. Interfere with all current GPS global positioning systems and Beidou positioning systems.
- 5. Suitable for 12V or 24V car, but it cannot exceed 24V.

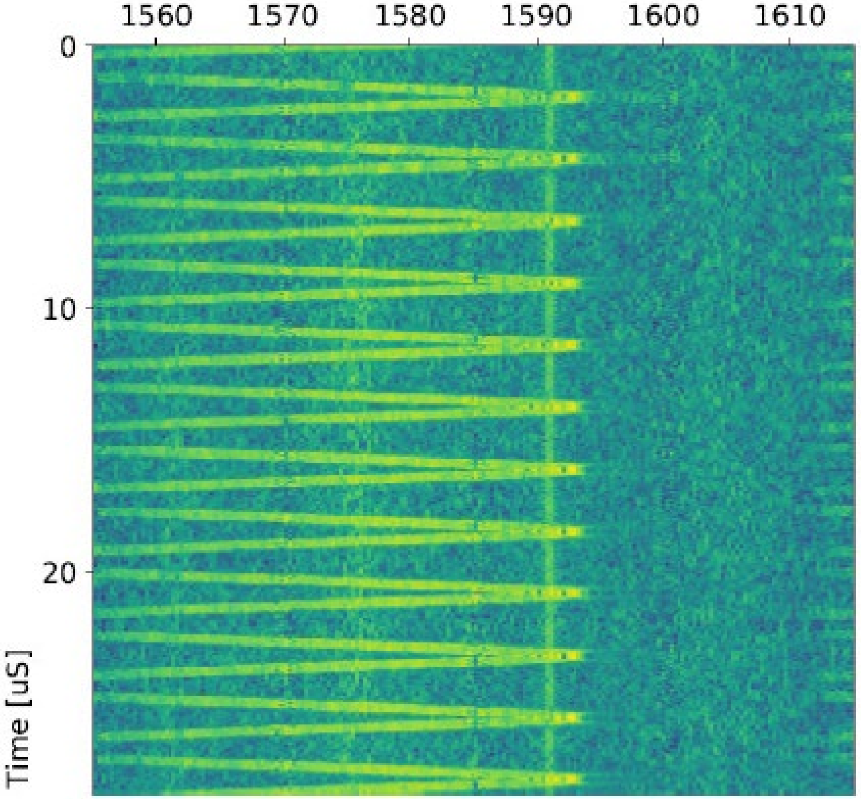
› See more product details

Getting Evidence Using Dedicated Equipment

- Example: European Union STRIKE3 program (H2020) found 160,000 GNSS interference events over 18 months in 14 countries.
  - "Standardisation of GNSS Threat reporting and Receiver testing through International Knowledge Exchange, Experimentation and Exploitation"

- Example: Norway's SINTEF
  - Finding evidence of PPD chirp jammers
  - tens of thousands of events *[SINTEF]*





[SINTEF]
Aiden J. Morrison, Nadezda Sokolova, Nicolai Gerrard, Anders Rødningsby, Christian Rost, Laura Ruotsalainen, "RFI Considerations for Utility of the Galileo E6 Signal," ION GNSS+ 2021.

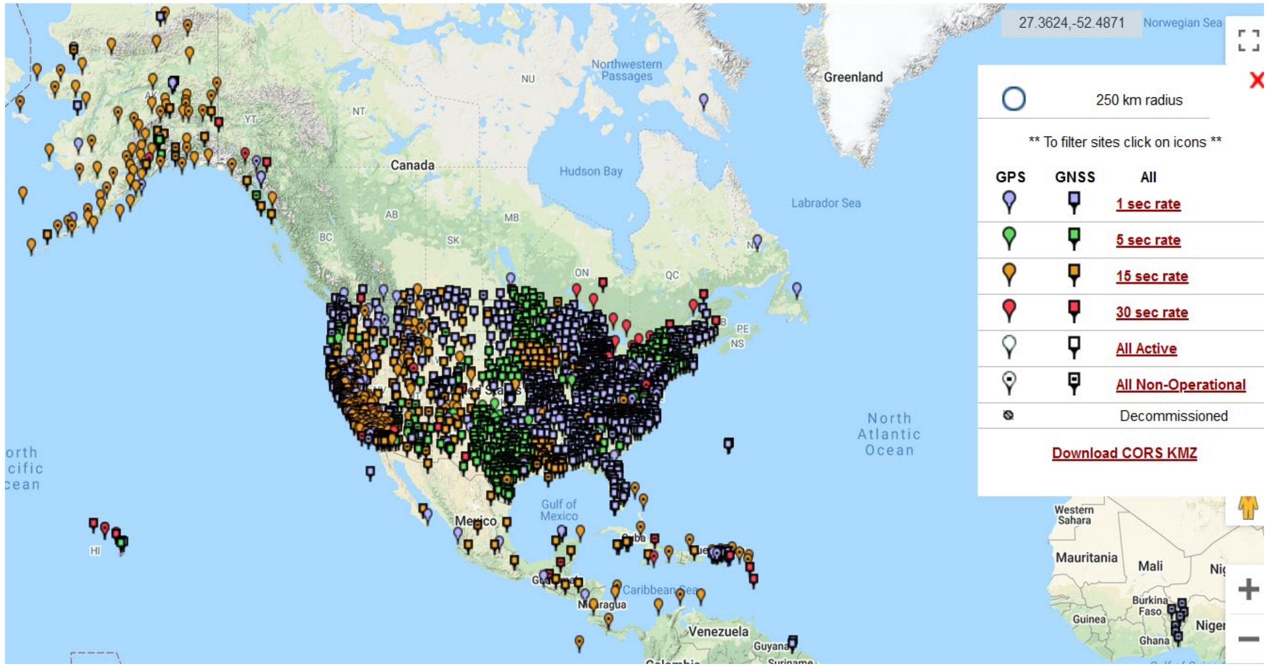
Evaluation Using NGS CORS Site Data

- We leverage **a receiver networks** providing publicly-available data
  - signal quality “C/N0” data
  - no RF front end data (still better than NIC)

- We want to improve detection using a receiver network as compared to a single receiver:
  - We want to **identify temporal an spatial interference patterns**

- To **prove the presence** of RFI:
  - We will **predict RFI,** and deploy our equipment

Map of CORS Network Reference Stations



○ 250 km radius

** To filter sites click on icons **

GPS	GNSS	All
		1 sec rate
		5 sec rate
		15 sec rate
		30 sec rate
		All Active
		All Non-Operational
		Decommissioned

Download CORS KMZ

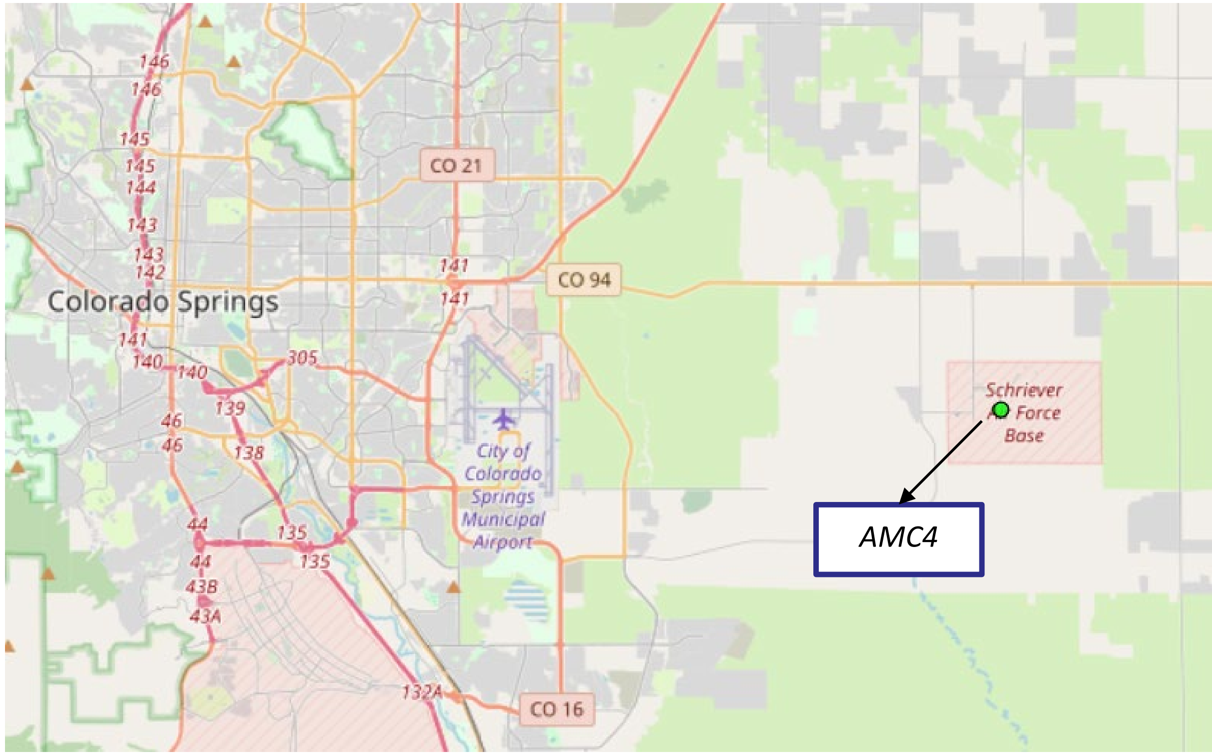
Source: https://www.ngs.noaa.gov/CORS_Map/

*NOAA National Geodetic Survey (**NGS**) Continuously Operating Reference Stations (**CORS**) is a network of ~2000 reference stations.*

Jada, S., Psiaki, M., Landerkin, S., Langel, S., Scholz, A., & Joerger, M. (2021, September). Evaluation of PNT Situational Awareness Algorithms and Methods. In *ION GNSS+ 2021*

Jamming Detection on US Highways Using CORS and IGS Data

- We designed a C/N0-based jamming detectors *[Jada 2021]*:
  - **highly-sensitive** (locally Neyman-Pearson optimal)
  - ensuring a **quantifiable risk of false alerts**
- The monitor **is self-calibrating**:
  - a **high-fidelity** mean-C/N0 model and a **robust** probabilistic model of nominal deviations
  - automatically adjusts to different receivers, antennas, local multipath environments
- We processed data from **900 stations** along US highways



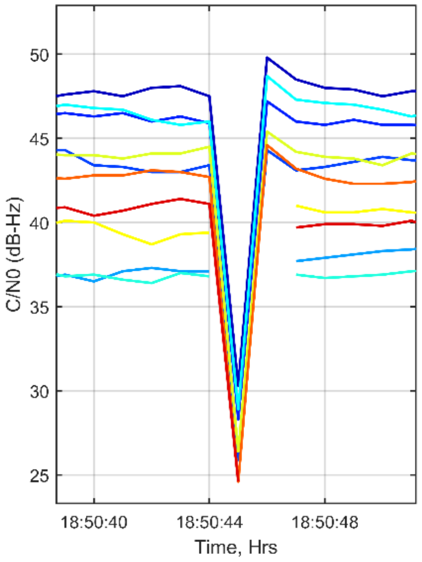
The IGS (International GNSS Service) site lies near a highway. We could deploy our equipment on a parking lot near the highway.

[Jada 2021] Jada, S., Psiaki, M., Landerkin, S., Langel, S., Scholz, A., & Joerger, M. (2021, September). Evaluation of PNT Situational Awareness Algorithms and Methods. In *ION GNSS+ 2021*

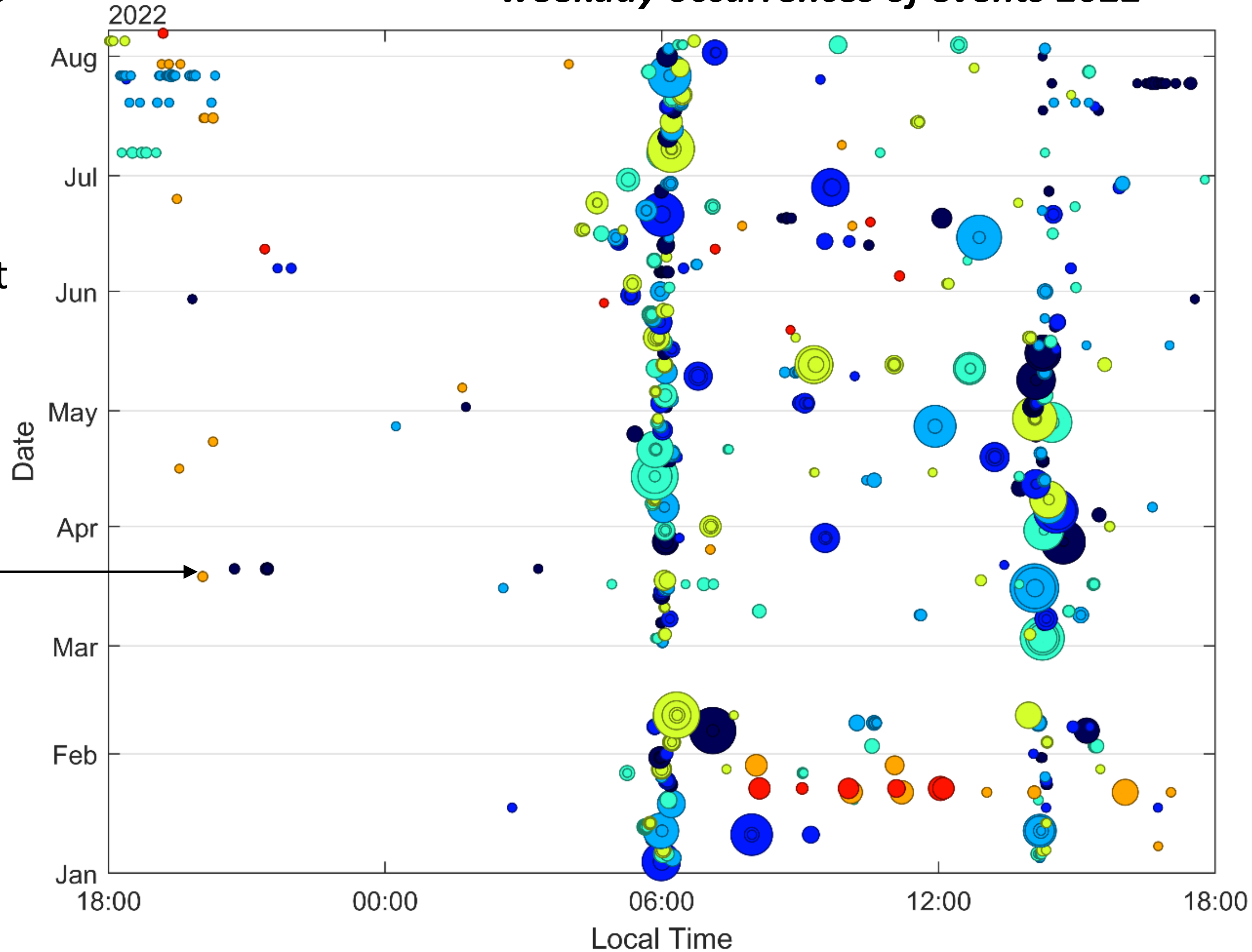
IGS Data Analysis: Colorado Springs

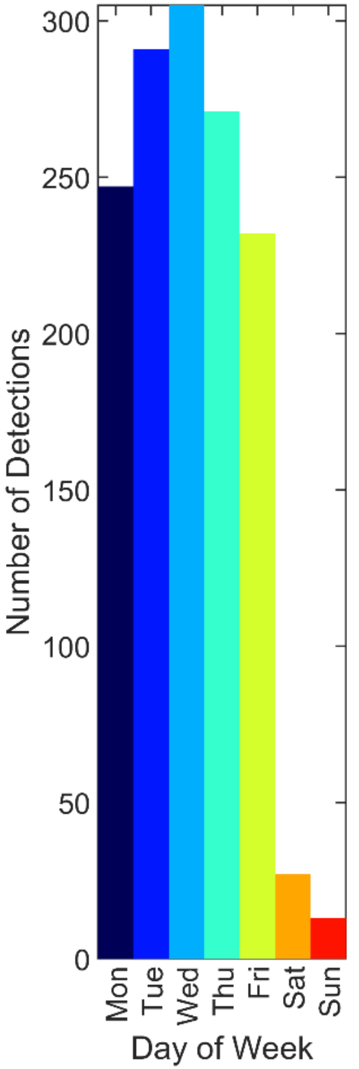
- We found RFI patterns at an IGS station in Colorado Springs, CO.
  - RFI: 6:00 am and 2:00 pm on weekdays over the past 8 months.

Example event



C/N0-based jamming detector results showing ***weekday occurrences of events 2022***





[Jada 2022] Jada, S., Bowman, J., Psiaki, M., Fan, C., Joerger, M. "Time-Frequency Analysis of GNSS Jamming Events Detected on US Highways." In *ION GNSS+ 2022*

Wideband RF Data Collection Hardware

- To characterize GPS interference, we designed a **portable wideband RF data collection setup**
  - using a **Universal Software Radio Peripheral (USRP)**
  - a non-GPS-disciplined osccillator
  - an extra COTS (commercial off-the-shelf) receiver
- We designed a process to store memory-expensive wideband RF data
  - activated by an RF-signal **power-based detector**

Tallysman 33-8829NMAT

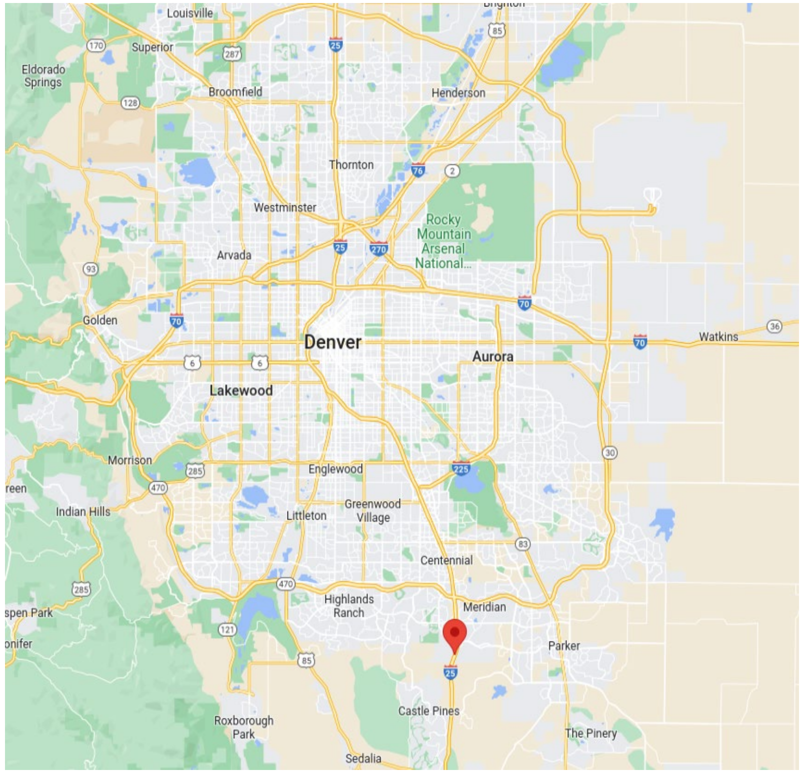
Connor Winfield OCXO-OH100

Ettus USRP N200 + DBSRX2 Daughter Board

Intel Next Unit in Computing - 6 (NUC6)

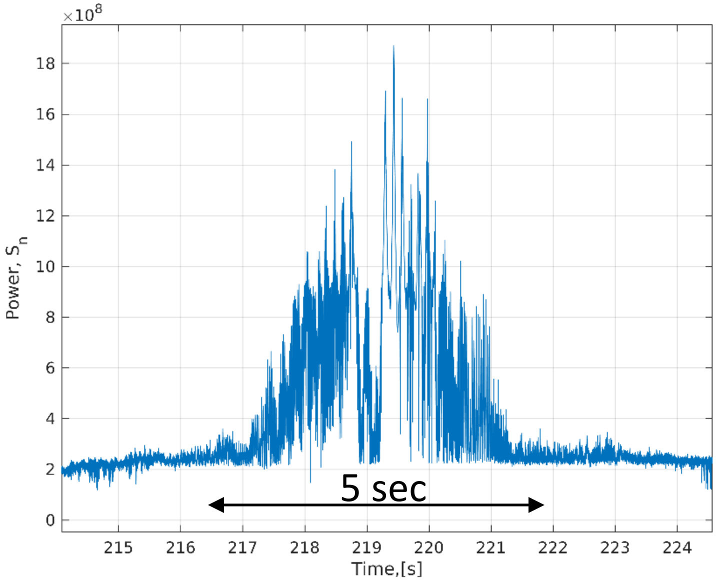
u-blox EVK M8F

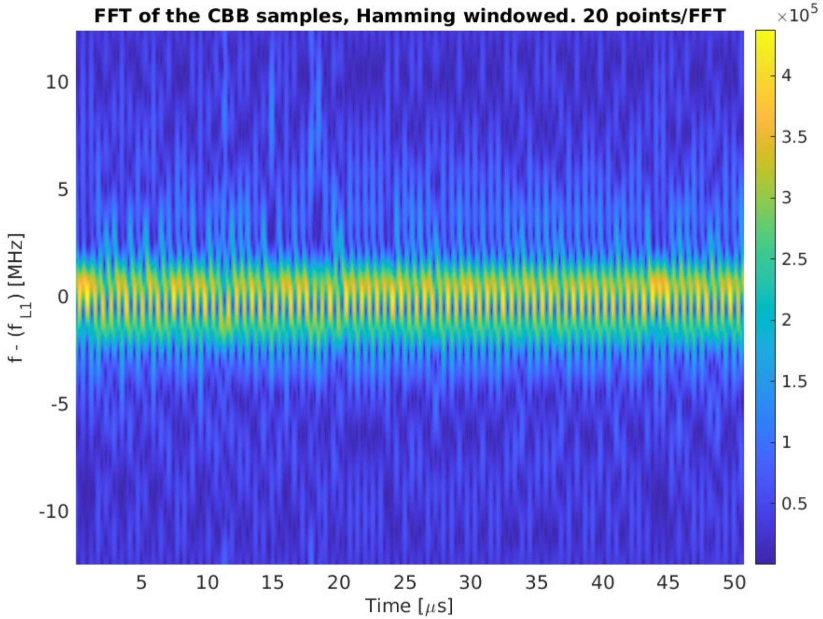
Spectrogram of a PPD Jamming Signal

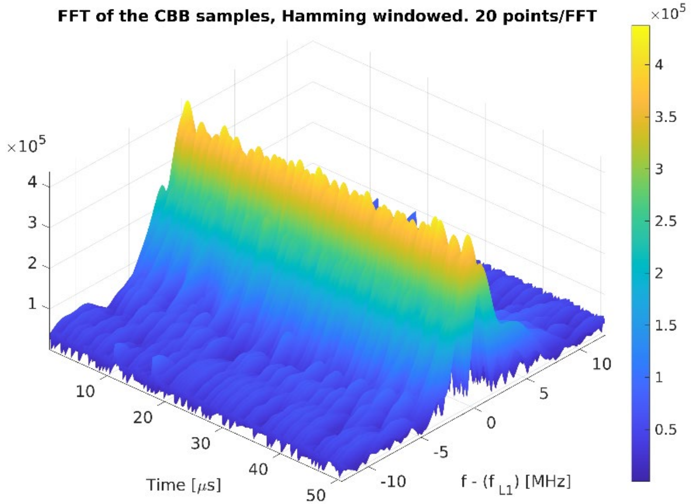


We identified a PPD near Denver on Interstate I-25, on September 21, 2022 at 8 AM**.**

Antennas mounted on our car







Conclusion

- GNSS plays a key role in **localization and coordination**
  - Positioning, Navigation, and Timing (PNT) infrastructure must be “**protected, toughened, and augmented**”

- Crowdsourced data from ADS-B (and cell-phone) can be used to detect and localize suspected jamming and spoofing
  - detection is **only possible a-posteriori, for wide-scale events**
    - proof of jamming comes from the number of impacted users
  - detection is not obvious for localized, temporary events

- We used publicly available data to **predict jamming events** on US highways
  - We then used our own equipment to observe and **identify jammers**

Way Forward

- There are numerous **connected GNSS receiver networks** that could be leverage for RFI monitoring
  - **traffic management** (ADS-B, AIS, in the near-term future: cars/trucks) and **scientific purposes** (CORS, IGS)
  - **differential GNSS** networks, **cell phone** towers (even cell phone users), etc.

- **Suggestions** --- we would improve GNSS RFI monitoring by:
  - designing messaging standards to include GNSS signal quality data fields (C/N0, AGC, RF front end bandwidth)
    - Radio Tech. Comm. for Marit. Serv.: **RTCM SC-134**, Integrity for GNSS-based High Accuracy Applications
    - **NMEA** (National Marine Electronics Association) – message proposed by Dong Kyeong Lee (UC Boulder)
  - developing **dedicated, robust** data collection and **low-latency sharing** systems
  - **coordinating data-monitoring** efforts and **alerting** system