

Jammer on the Horizon: A Robust Method for GPS Jammer Localization Using ADS-B Data

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joint work with

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<https://sero-systems.de>

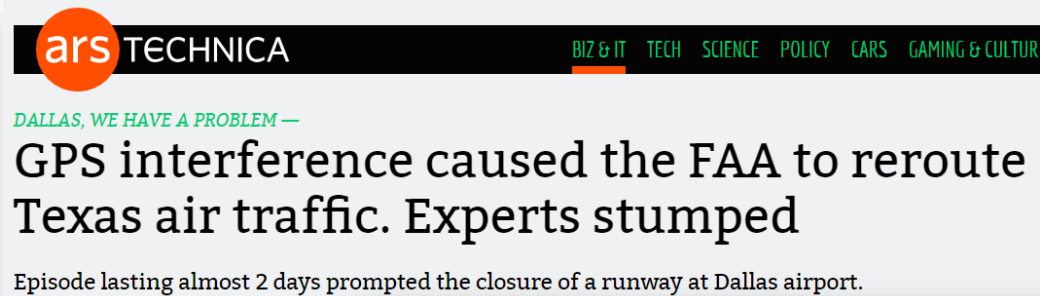
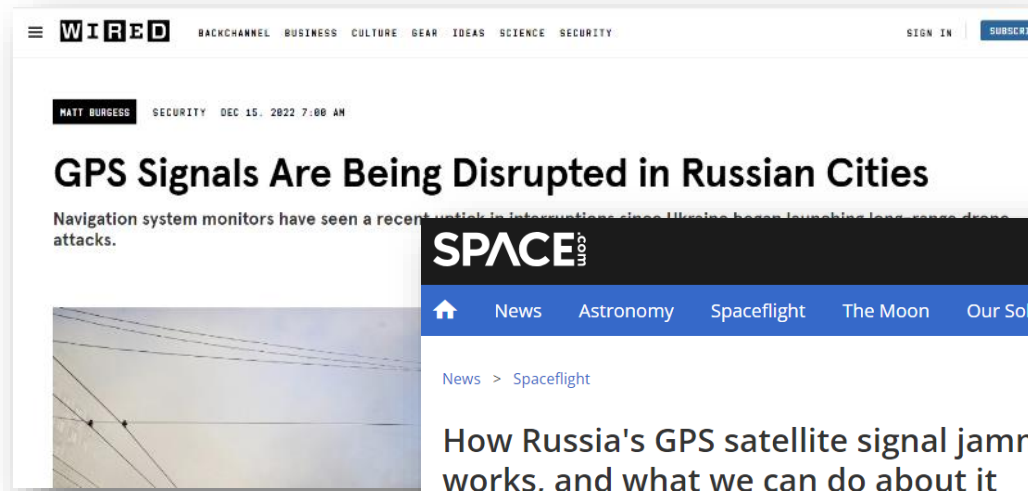
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Why Should We Care About GPS Jamming?

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Notice To Airmen 21 January 2022
NAV GPS UNREL(INCLUDING WAAS, GBAS, AND ADS-B) MAY NOT BE AVBL WI A 50NM RADIUS
CENTERED AT 394900N1044000W OR ALL QUADRANTS OF THE DEN VOR SFC-FL400. 22 JAN
05:00 2022 UNTIL 01 FEB 05:00 2022. CREATED: 22 JAN 05:33 2022

Executive Order on Strengthening National Resilience through Responsible Use of Positioning, Navigation, and Timing Services

[INFRASTRUCTURE & TECHNOLOGY](#)

Issued on: February 12, 2020



Safety Information Bulletin Operations – ATM/ANS

SIB No.: 2022-02

Issued: 17 March 2022

Subject: Global Navigation Satellite System Outage Leading to Navigation / Surveillance Degradation

Beyond the Jam: Threat Types, Impacts and Our Focus 3

Unintentional Interference:

- Uncharacterized

<https://www.sparkfun.com/>



<https://www.jammer4uk.com/>



Criminals:

- Cheap equipment (< \$1000)
- Medium power (< 100 W)
- Self-protection, manipulation
- Targeted or untargeted

Script Kiddies / Hobbyists:

- Cheap equipment (< \$500)
- Low power (max. 100 mW)
- No malicious intentions
- No specific target

Electronic Warfare:

- Expensive military equipment
- High power (> 1000 W)
- Various intents (attack or protection)
- Typically targeted

Wikipedia: Zhitel jammer



Focus of this work!



- The three takeaways from this presentation:
 1. How to detect GPS jamming in real-time and over large areas
 2. The problem may be bigger than you think!
 3. What you can do to find the source of the jamming

PART 1: HOW TO DETECT LARGE GPS RFI EVENTS

Interference Hunting — The Old Way

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Src: Rhode & Schwarz

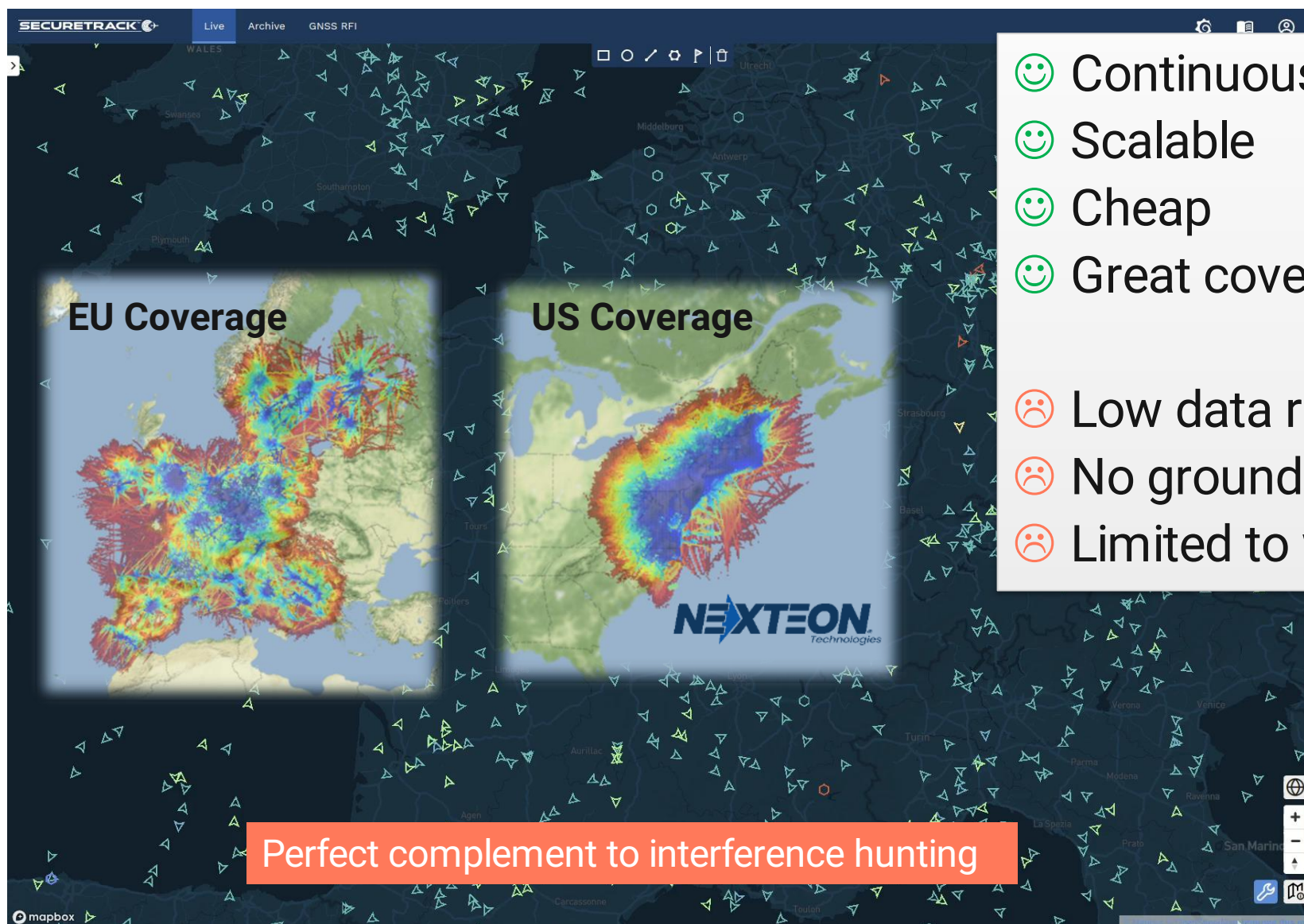


Src: Rhode & Schwarz

- 😊 Very high data resolution
- 😊 Ground truth
- 😞 On-demand only
- 😞 Expensive
- 😞 Slow
- 😞 Not scalable
- 😞 Limited to your jurisdiction

Leveraging Aircraft for GPS RFI Detection

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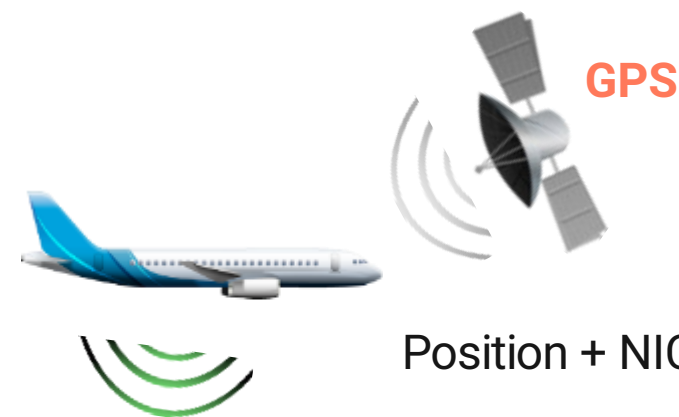
- 😊 Continuous and real-time
- 😊 Scalable
- 😊 Cheap
- 😊 Great coverage
- 😞 Low data resolution
- 😞 No ground truth
- 😞 Limited to where aircraft fly

GNSS RFI Monitoring Through ADS-B

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- Navigation Integrity Category (NIC)

- Reported along with all positions
- Indicates Containment Radius for the reported position



- NIC values under GNSS RFI

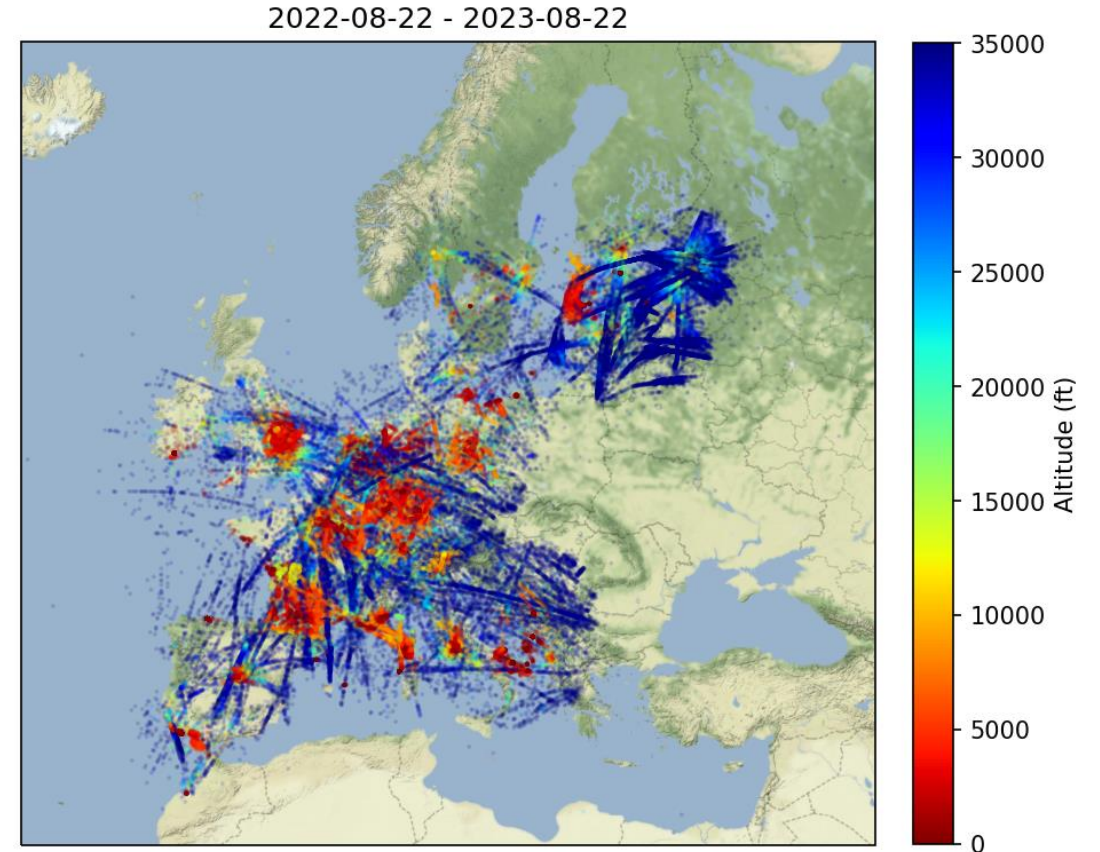
- Normal conditions: NIC = 7-10
- GNSS RFI: NIC values drops
- NIC = 0 when no GPS fix (DoS)

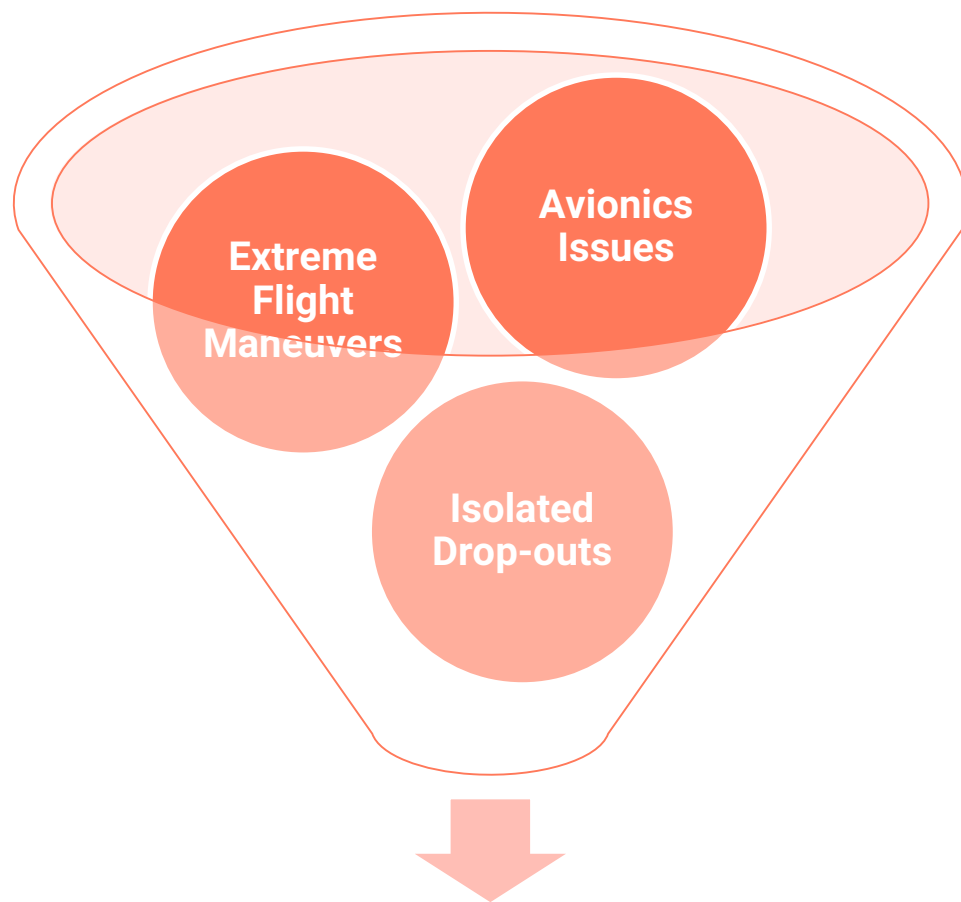
- We consider drop of NIC value below 6 an anomaly

NIC (Notes 1, 2)	Horizontal and Vertical Containment Bounds
0	$R_C \geq 37.04 \text{ km (20 NM)}$
1	$R_C < 37.04 \text{ km (20 NM)}$
2	$R_C < 14.816 \text{ km (8 NM)}$
3	$R_C < 7.408 \text{ km (4 NM)}$
4	$R_C < 3.704 \text{ km (2 NM)}$
5	$R_C < 1852 \text{ m (1 NM)}$
6	$R_C < 1111.2 \text{ m (0.6 NM)}$
7	$R_C < 370.4 \text{ m (0.2 NM)}$
8	$R_C < 185.2 \text{ m (0.1 NM)}$
9	$R_C < 75 \text{ m and VPL} < 112 \text{ m}$
10	$R_C < 25 \text{ m and VPL} < 37.5 \text{ m}$
11	$R_C < 7.5 \text{ m and VPL} < 11 \text{ m}$

NIC Anomalies — Observations from 1 Year of Monitoring 9

- SecureTrack recorded 311,925 anomalies (avg: 854/day)
- Most anomalies are noise
 - Anomaly density correlates with traffic density
 - Short, isolated drop outs of under a minute
 - Aircraft with persistent avionics issues
- Just underscores the “unreliability” of ADS-B as surveillance tech
- Useless for GPS interference event detection without further filtering





Potential GPS RFI

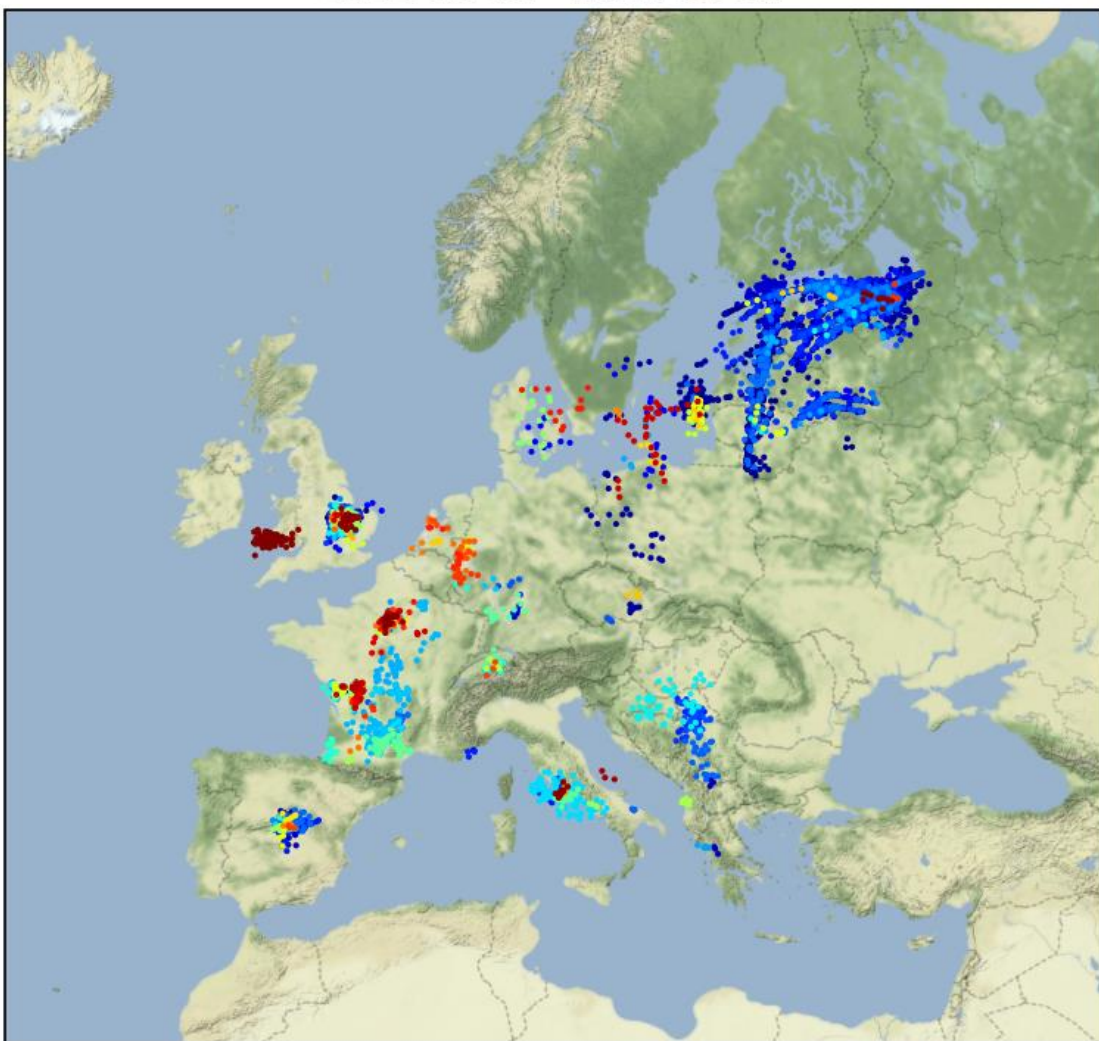
1. Detect and remove aircraft with avionics issues
2. Detect and remove aircraft performing extreme flight maneuvers
3. Perform agglomerative clustering to detect and remove single isolated events (both in space and time)

PART 2: HOW BIG IS THE PROBLEM?

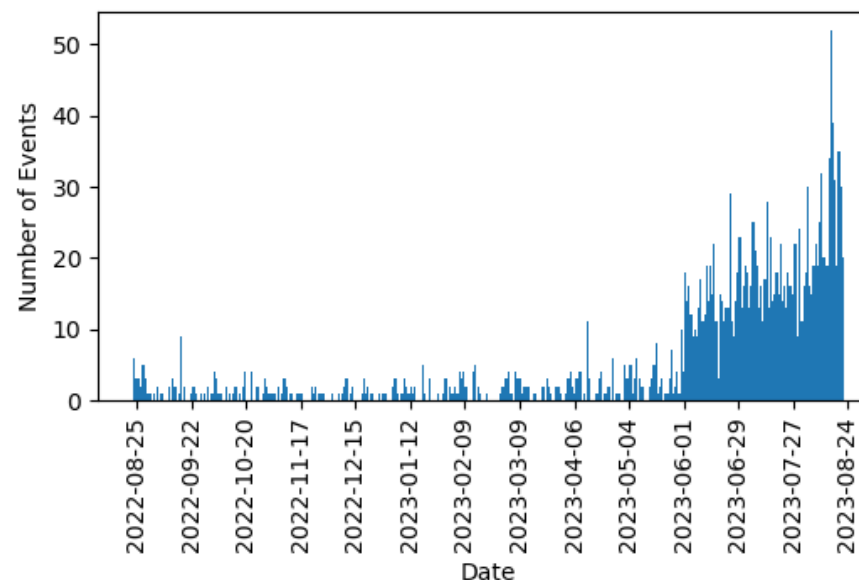
Detected GPS Jamming Events

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2022-08-22 - 2023-08-22



- Our monitoring system registered events on 263 of the 365 days
- Detections in almost every country we have coverage in
- Extreme activity increase in Northeast Europe since June 1:



PART 3: HOW TO LOCALIZE THE JAMMER

- As of this writing, about 11 papers on ADS-B-based jamming detection and 7 of them also provide approaches for locating the jammer:

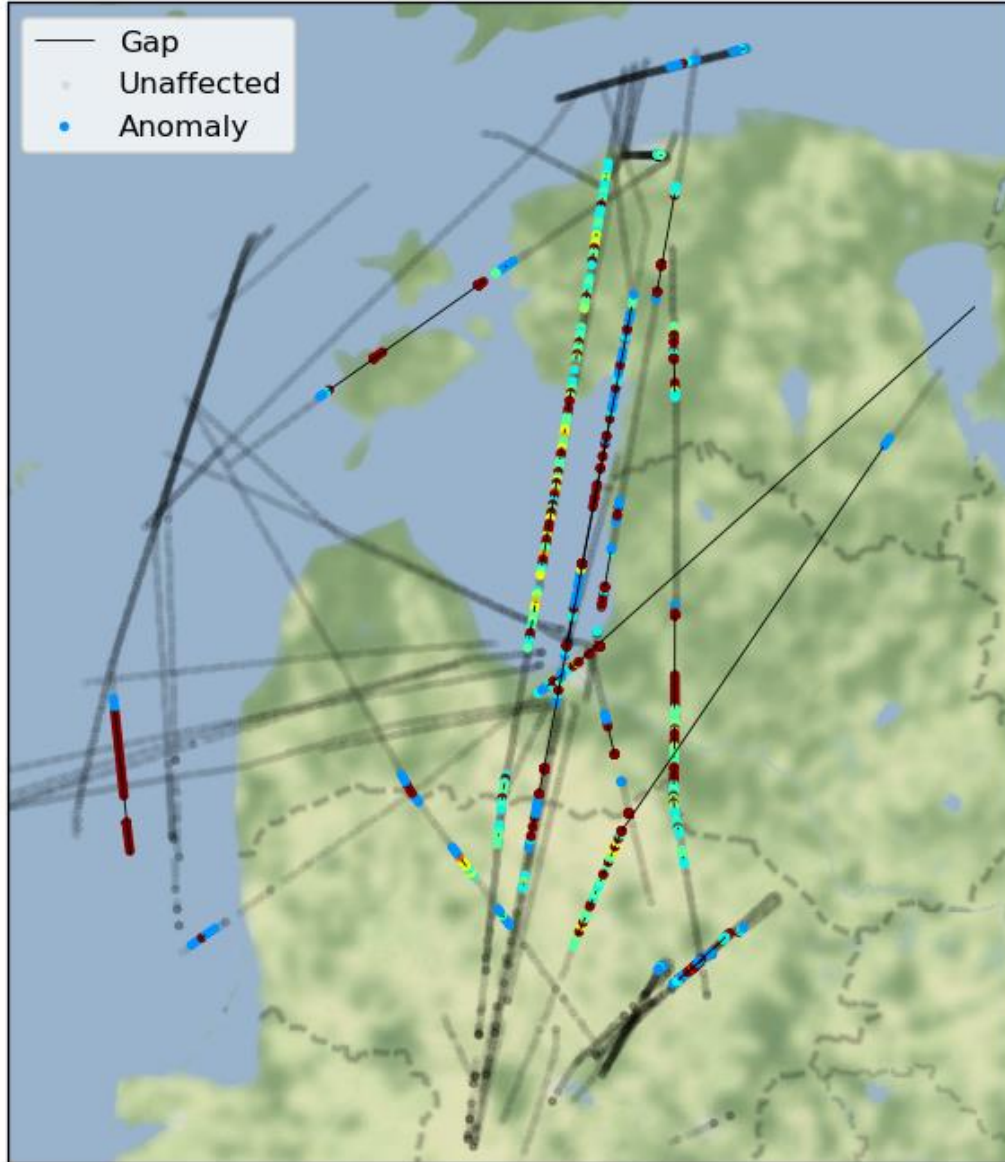
Reference	Parameter	Localization	Localization Method
Jonáš and Vitan (2019)	Gaps	yes	Signal strength modelling
Darabseh et al. (2019)	NACp	no	-
Liu et al. (2020)	NIC	yes	Centroid of affected region
Lukeš et al. (2020)	NACp	no	-
Liu et al. (2021)	NIC	yes	Machine learning
Liu et al. (2022a)	NIC	yes	Signal strength modelling
Liu et al. (2022b)	NIC	yes	Bayesian + Signal strength modelling
Dacus et al. (2022)	NIC	yes	Centroid of affected region
Figuet et al. (2022)	NACp	no	-
Fol and Felux (2022)	NACp + SIL	no	-
Liu et al. (2023)	NIC	yes	Signal strength modelling

Table 1: Overview of the literature on GNSS RFI detection and source localization through ADS-B data.

- Most common methods: Signal strength modelling and centroid calculation
- These localization approaches have limitations:
 - Jammer signal strength almost impossible to predict in the real-world
 - Centroid calculation affected by shape of affected area and traffic

Jamming Event in Northeast Europe on Jan 9, 2023

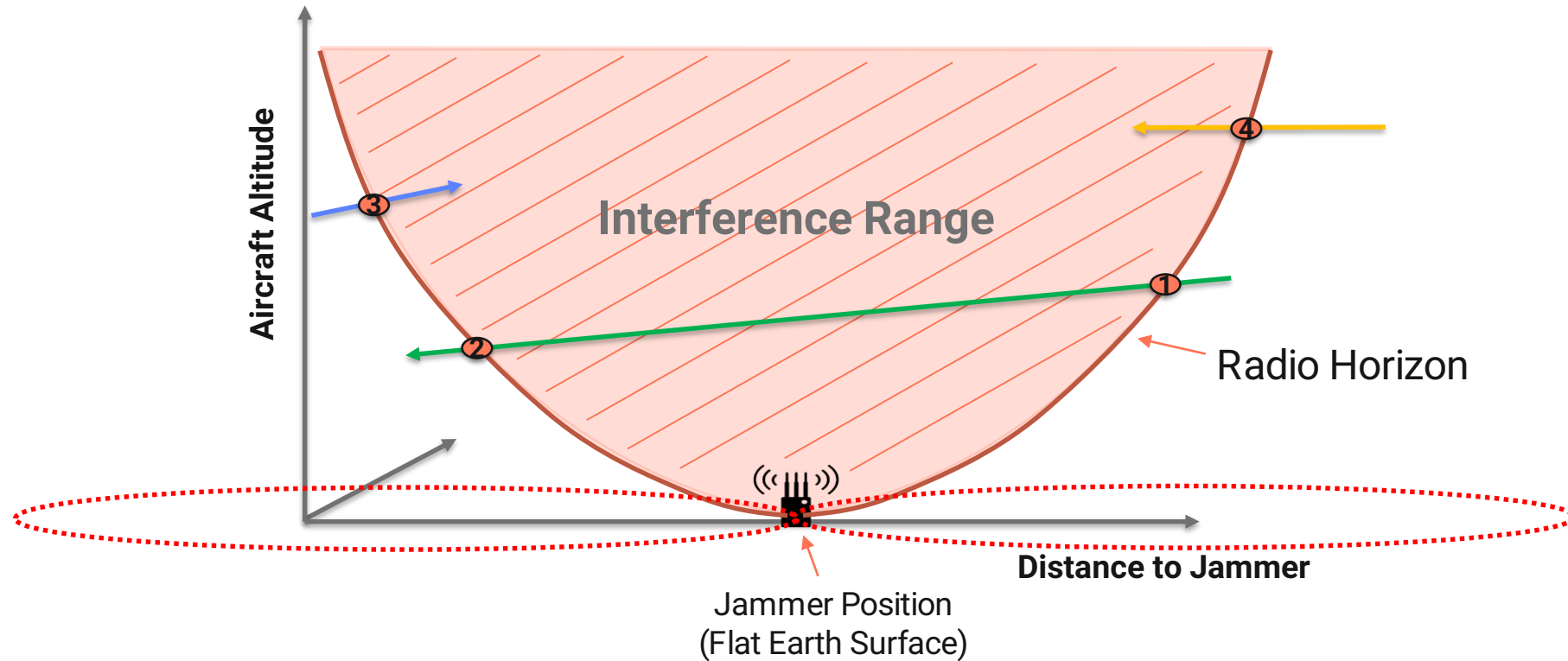
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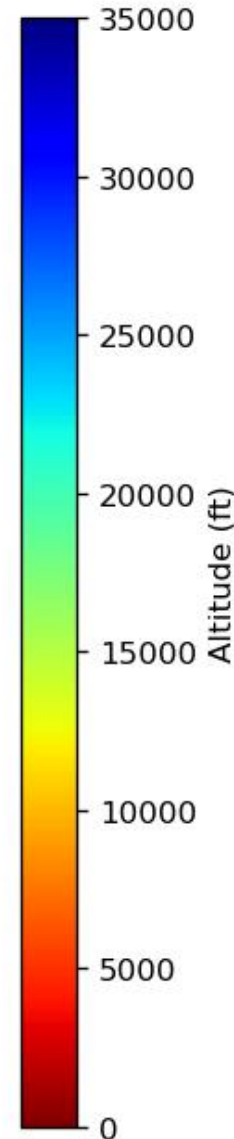
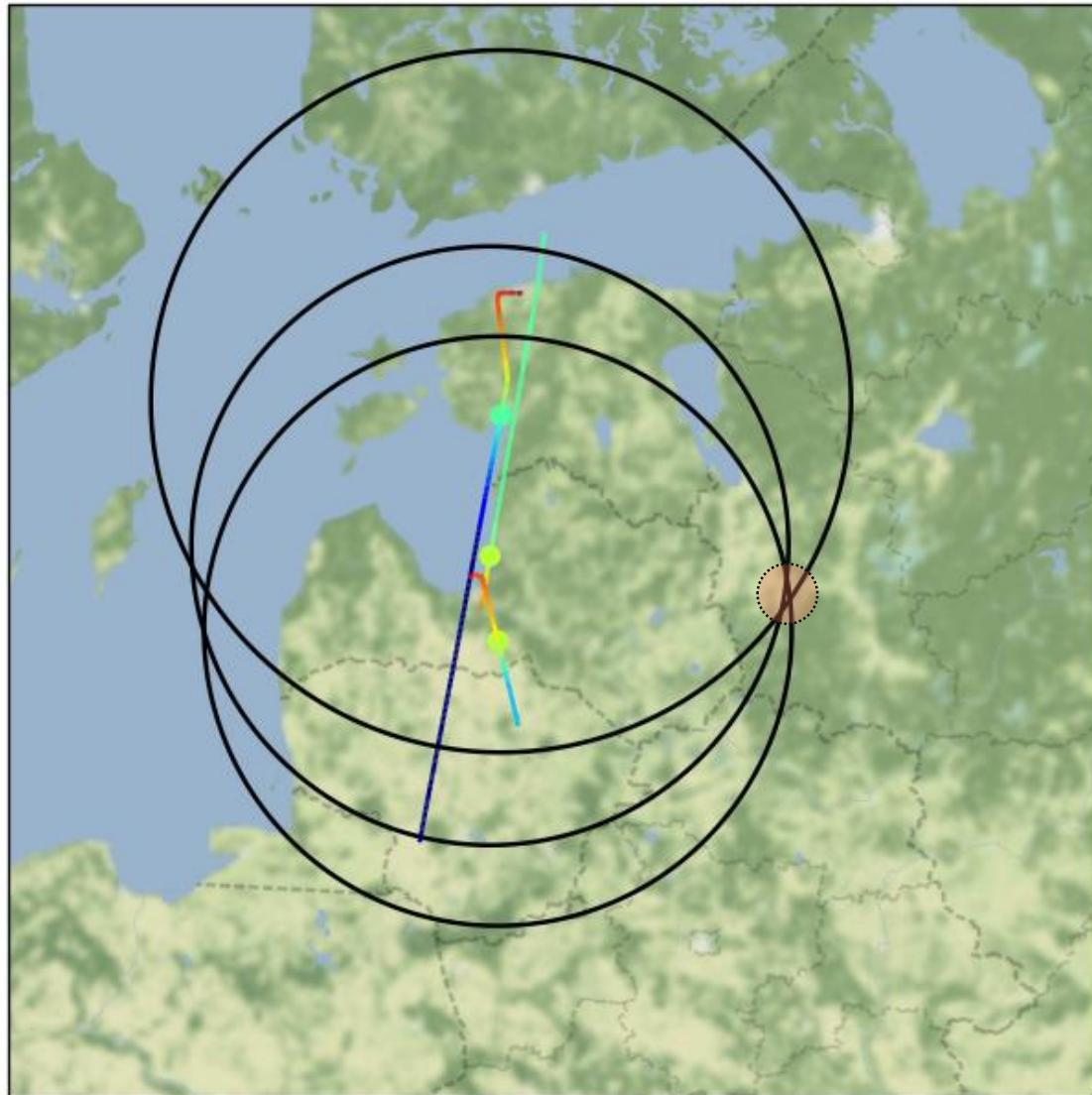
- 1h event affecting all three Baltic states between 7:40 and 8:40am
- Map on the left shows all traffic that was around in the region at that time
- ☹ Sparse traffic
- ☹ Traffic only on main routes
- ☹ Incomplete coverage



Incomplete picture renders shape-based approaches unusable



Basic Idea: Collect samples of the radio horizon of the jammer to infer its location.



- All three circles roughly intersect at the same location in the East
→ can be correlated with infrastructure
- Second “intersection” in the West due to vertical traffic shape
→ ruled out due to lack of DoS in West
- Selection of samples critical — if number of samples is small
→ make sure they actually represent the horizon



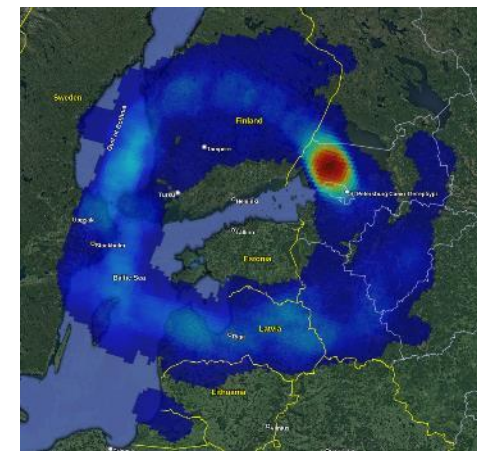
NIC Anomalies
2023-07-23

1. Select Samples
2. Calculate Horizon



Radio Horizons of
Aircraft

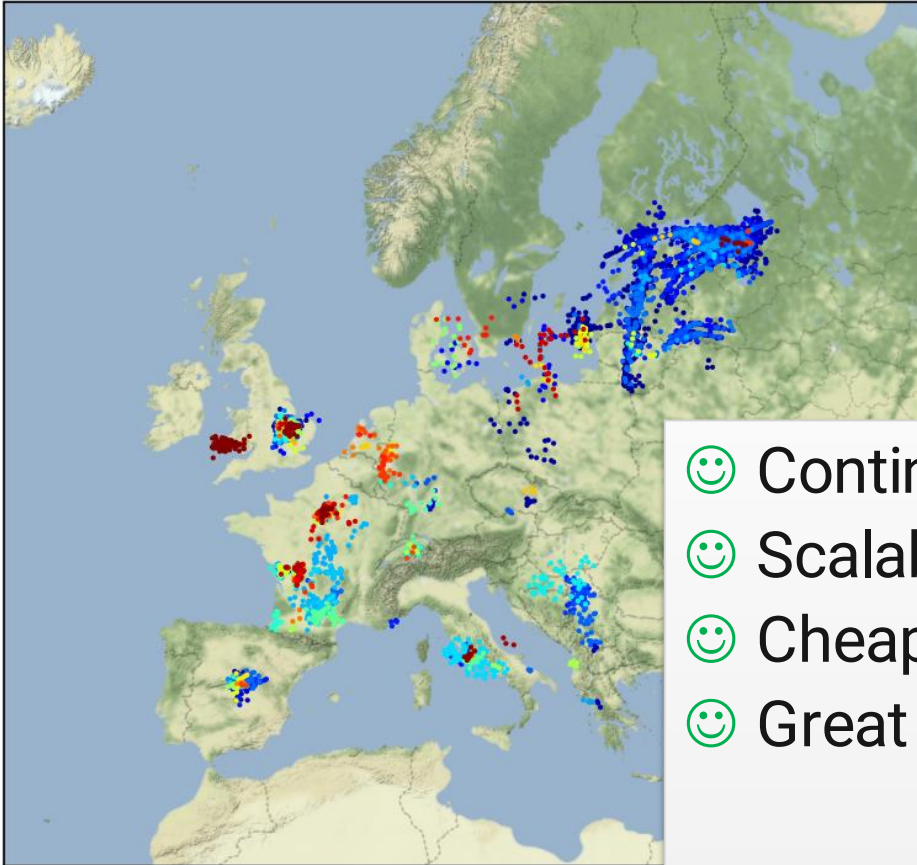
3. Intersect Horizons
4. Calculate Density



Jammer Location
Likelihood (10s of km)

Location can be further narrowed down by correlating the high density area with additional information, such as:

- Satellite imagery
- Known locations of military infrastructure
- Public reports and social media
- Triangulation using satellites, aircraft or HABs



ADS-B is great data source for GPS interference monitoring

Source localization possible, but no catch-all solution (applicable method depends on situation)

- 😊 Continuous and real-time
- 😊 Scalable
- 😊 Cheap
- 😊 Great coverage
- 😞 Low data resolution
- 😞 Limited to where aircraft fly
- 😞 No ground truth

