

GNSS Vulnerabilities and Emerging Threats

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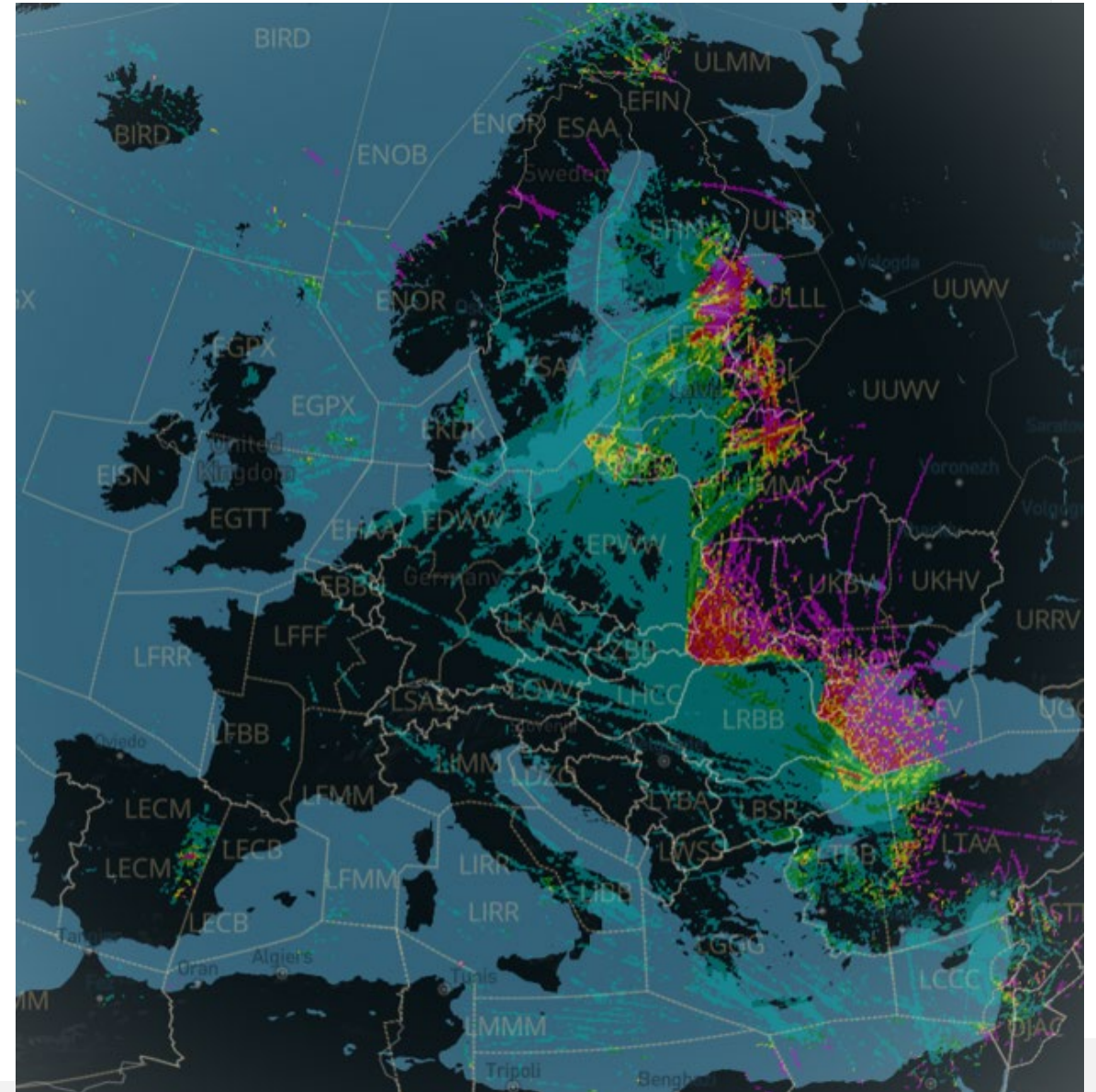
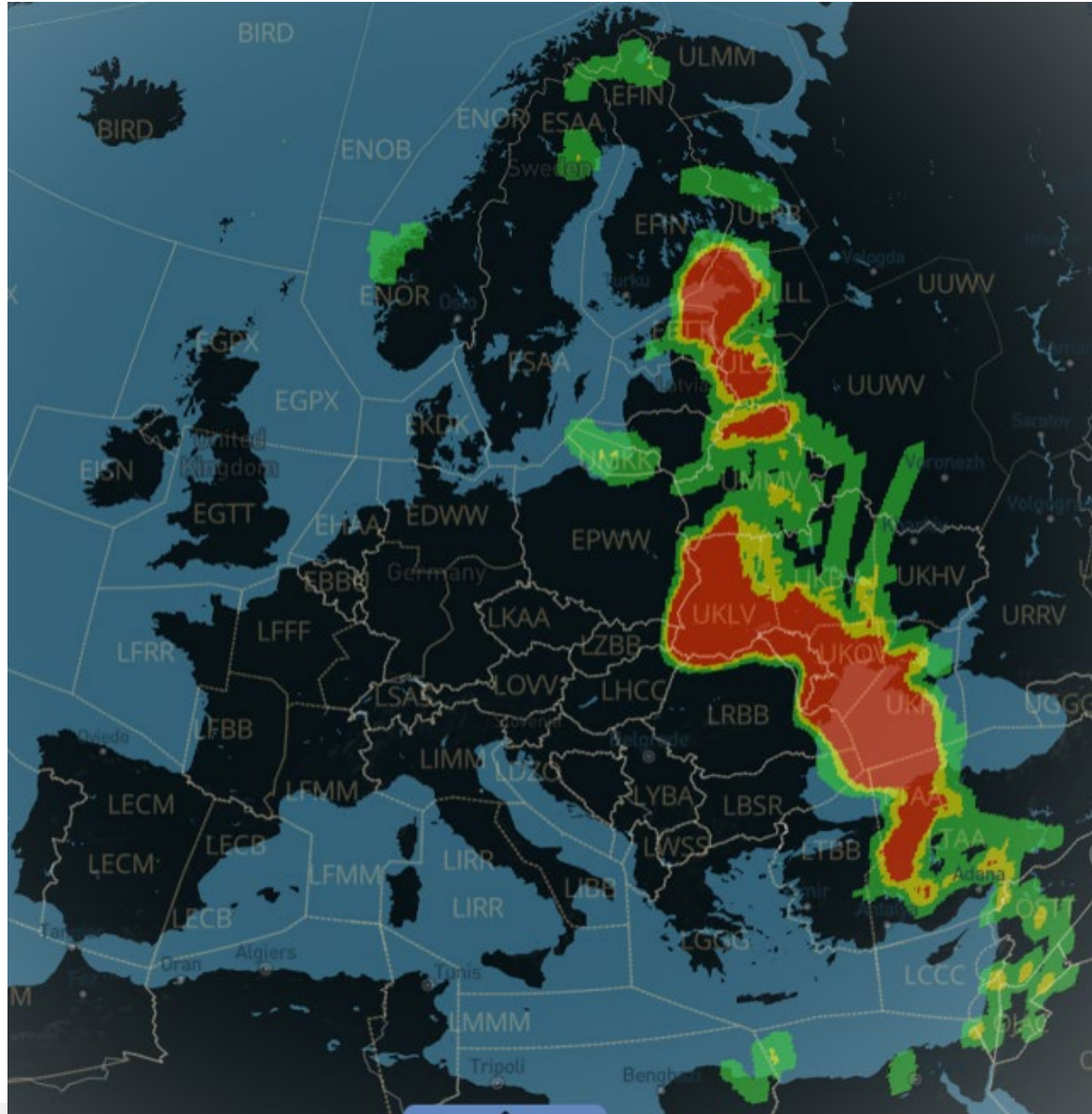
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Important Notice

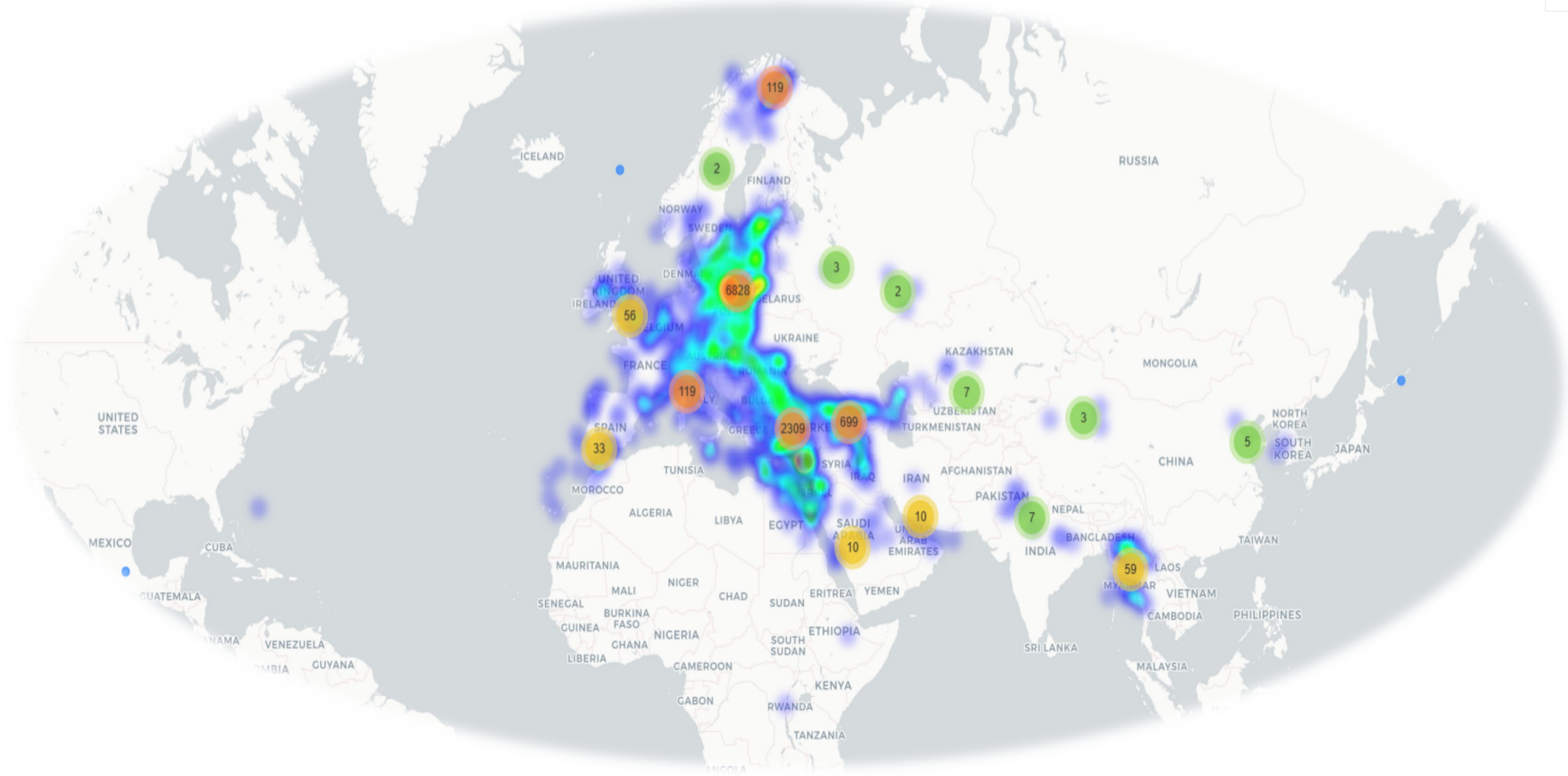
- Information in these slides is NOT INTENDED FOR THE GENERAL PUBLIC
- Goal of this sharing of sensitive information is to help aviation maintain safe operations
- Workshop Participants are requested to use the material with the necessary discretion, for aviation-internal SAFETY purposes ONLY

The GOOD NEWS FIRST

- Core Satellite Constellation Internal Faults
- Constellation Weakness (not enough satellites with good geometry)
- Space / Solar Weather and Ionospheric Effects
- Radio Frequency Interference (RFI)
- Mitigated by over 2 decades of Augmentation System Design
- GPS operating well above minimum constellation (24SV)
- DFMC will have plenty satellites
- Occasional issues in SBAS during solar peaks
- DFMC will fix all first order effects
- Current multi-sensor and independent CNS capabilities provide significant robustness (especially INS)
- DFMC: L5/E5 signal is stronger, ARAIM will have redundant Single Frequency Modes (+other stuff)

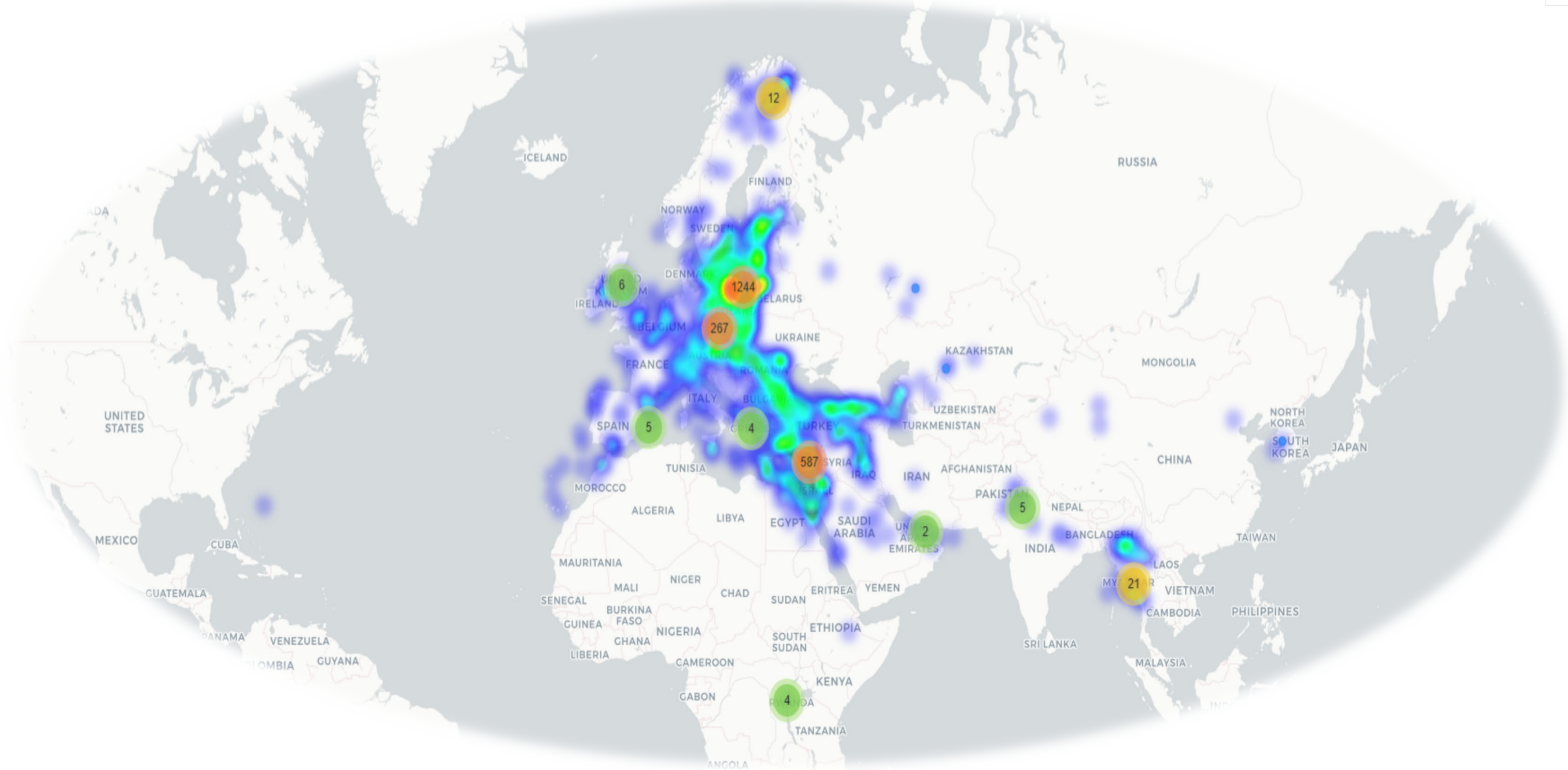


2024-2025 GNSS Jamming: Pilot Reports to EVAIR



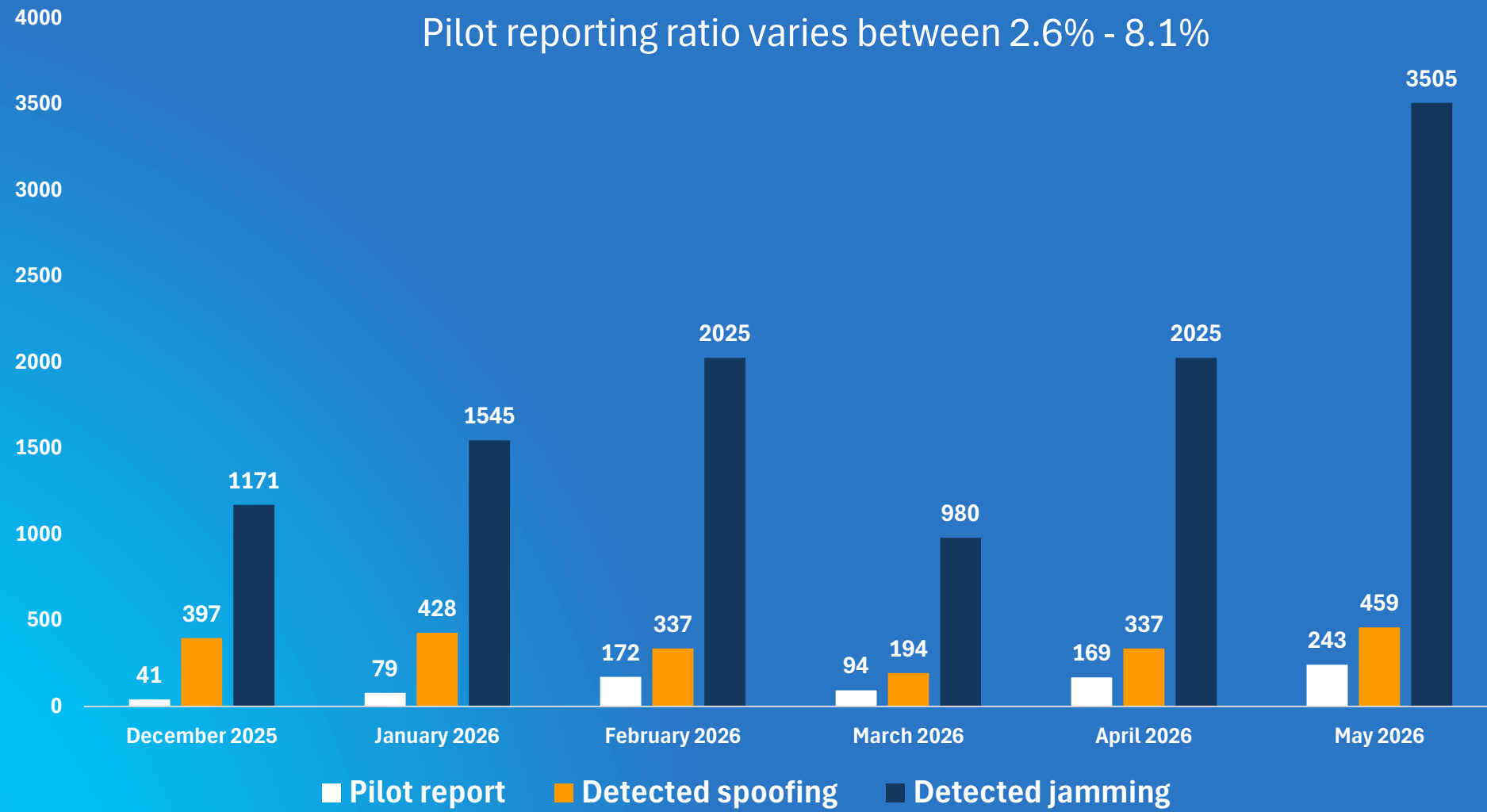
EVAIR = EUROCONTROL Voluntary ATM Incident Reporting System

2024-2025 GNSS Spoofing: Pilot Reports to EVAIR

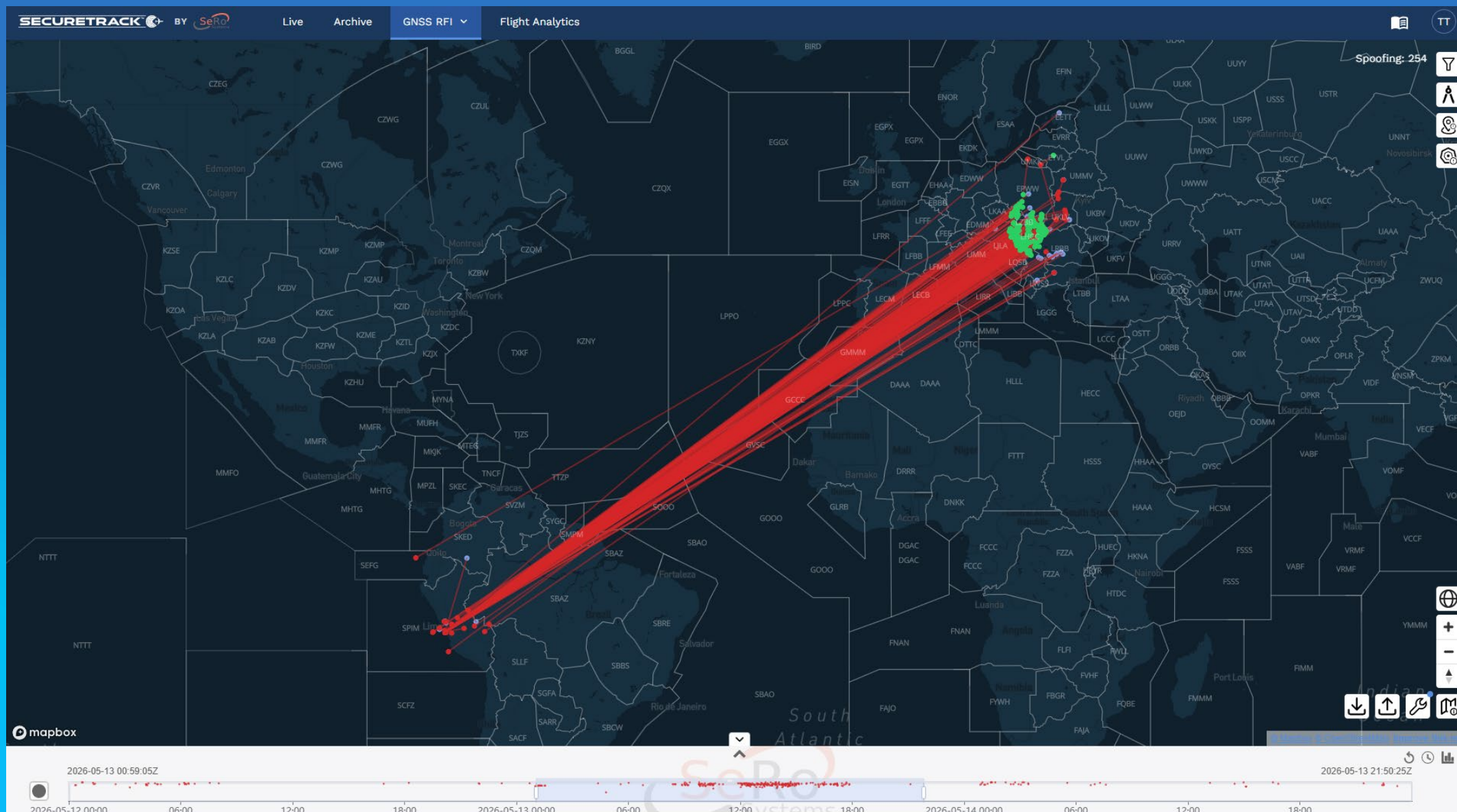


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GNSS RFI event reporting ratio

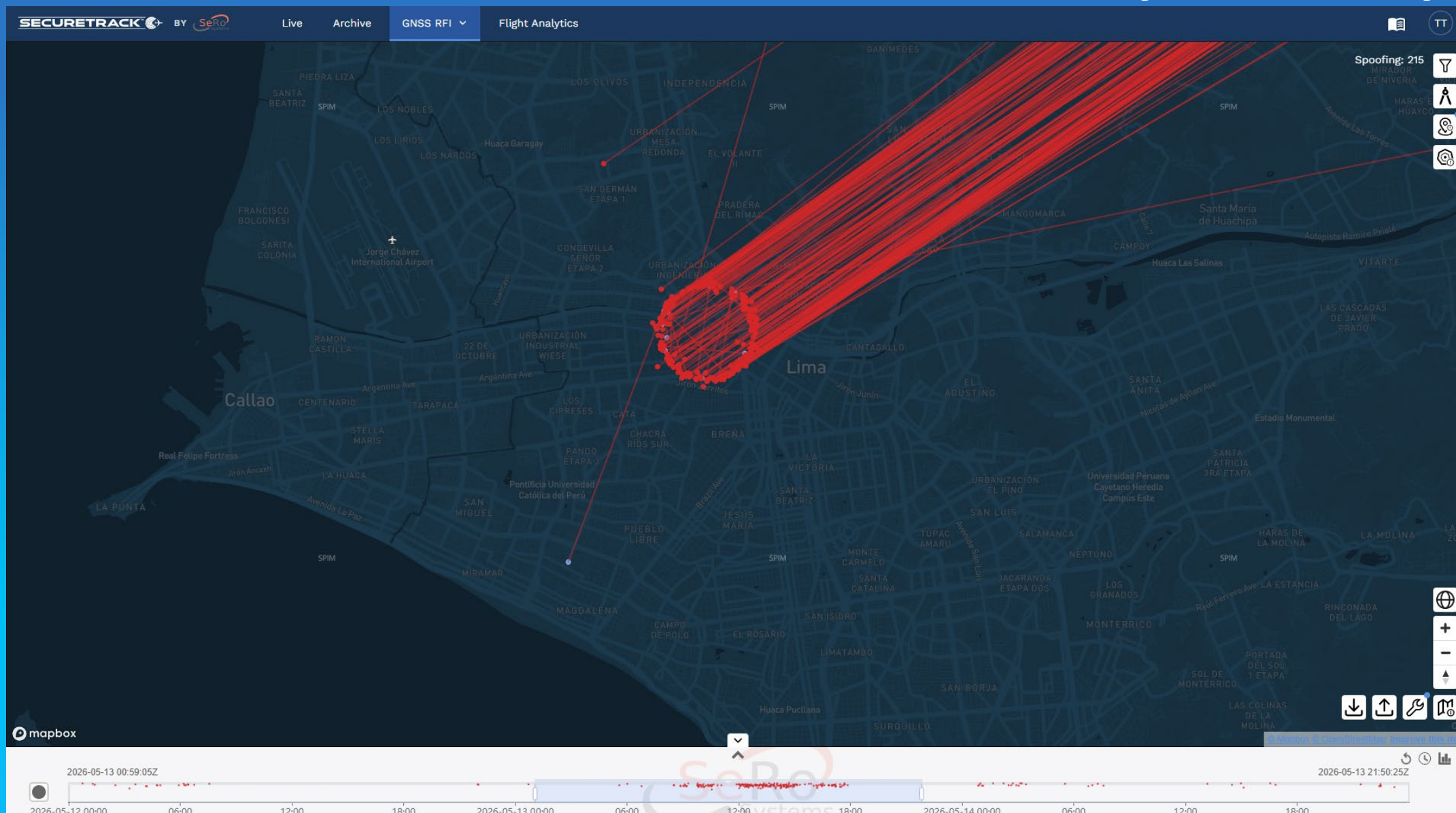


Post-event analysis: 13. May 2026

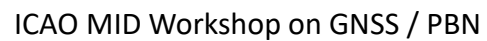


Source: SecureTrack developed by SERO GmbH.

Post-event analysis: 13. May 2026



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Persistent Impact of GPS Spoofing on Aircraft Navigation



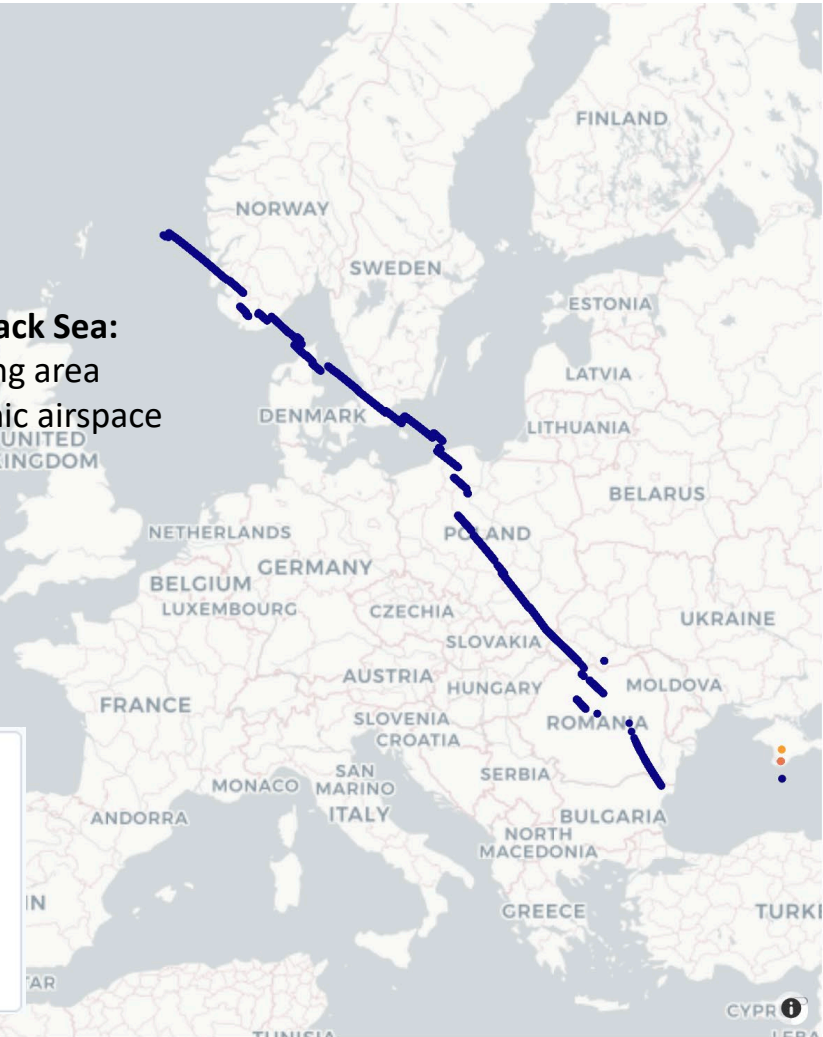
SKAI
DATA
SERVICES



School of
Engineering

Analysis of 397 transatlantic flights initially spoofed over the Black Sea:
≈74% broadcast a NIC ≥ 7 once they exited the jamming / spoofing area
≈10% were still broadcasting a NIC = 0 as they entered the Oceanic airspace
Remaining flights regained NIC ≥ 7 at various points over Europe
Provided by Skai Data Services (NSP JWG/13 IP15)

CPDLC Clock Shift Data:



Taking it to the individual Cockpit level:

Example of a report from a small business jet

During the arrival, when passing FL130, the aircraft experienced **total loss of GNSS navigation** due to GPS jamming. This affected multiple systems, such as **attitude and horizontal reference system (AHRS affected)**, **loss of obstacle and terrain awareness (TAWS inop)**, **loss of awareness aid synthetic vision (SVS inop)**, **loss of ADSB-OUT**, **loss of horizontal and vertical navigation capabilities (absence of VORs in the region, aircraft with no DME-DME navigation capability, limited inertial navigation capability)**.

ATC was advised and in the **aircraft was vectored** by the ATC until establishing the localiser. The GPS signal was restored once at low altitude (6000 ft).

GNSS Interference Impact on Aircraft and Operations

- GPS Receiver **fail**, FMS position **fail**, Clock **fail**: may remain
- GPWS **failure**
- Weather Radar **failure**
- Position reporting **failure** (ADS-C)
- Comms **failures** (CPDLC, SatCom)
- Head Up Display (HUD) **failure**
- Synthetic Vision System (SVS) **failure**
- Runway Protection Systems **failure** (RAAS, ROPS)
- Emergency Locator (ELT) reporting incorrect
- Wind Display (ND) **failure**
- ADS-B-out **failure**, ADS-B-in **failure**
- Transponder **failure**, Navaid tuning **failure**
- Unable to navigate normally (may need radar vectors to destination)
- No longer RNP capable (cannot cross North Atlantic RNP4)
- EGPWS false alerts, EGPWS system switched off
- Go-Arounds in unexpected positions
- Cascading system failures, complex and high workload approaches
- Weather Radar: unable to detect thunderstorms (CB's)
- Loss of comms: CPDLC, SatCom
- GPS receiver contamination possible
- Unable to de-select GPS input to aircraft systems
- Aircraft may be grounded pending hard reset of GPS receiver

Summary from OPSGROUP

Why are civil aircraft so exposed to interference?

Air Transport Aircraft
at En-Route Altitude
(no anti-jam capability)



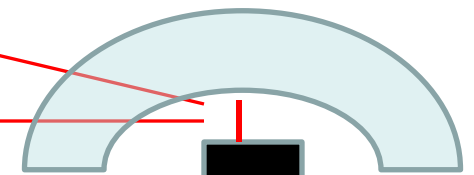
Jammer Power	Impact Radius on Aircraft at FL350 ¹	Maximum Outage Duration at ENR Speed ²	“Protection” against military GPS system near ground ³
10W	77NM	20min	20km
100W	230NM	1h	60km

1: Assuming -6dB antenna gain and 15dB tracking margin

2: ENR speed assumed 450 knots

3: Assuming a +20dB J/S capability (very modest!)

Drone with Anti-Jam Capability



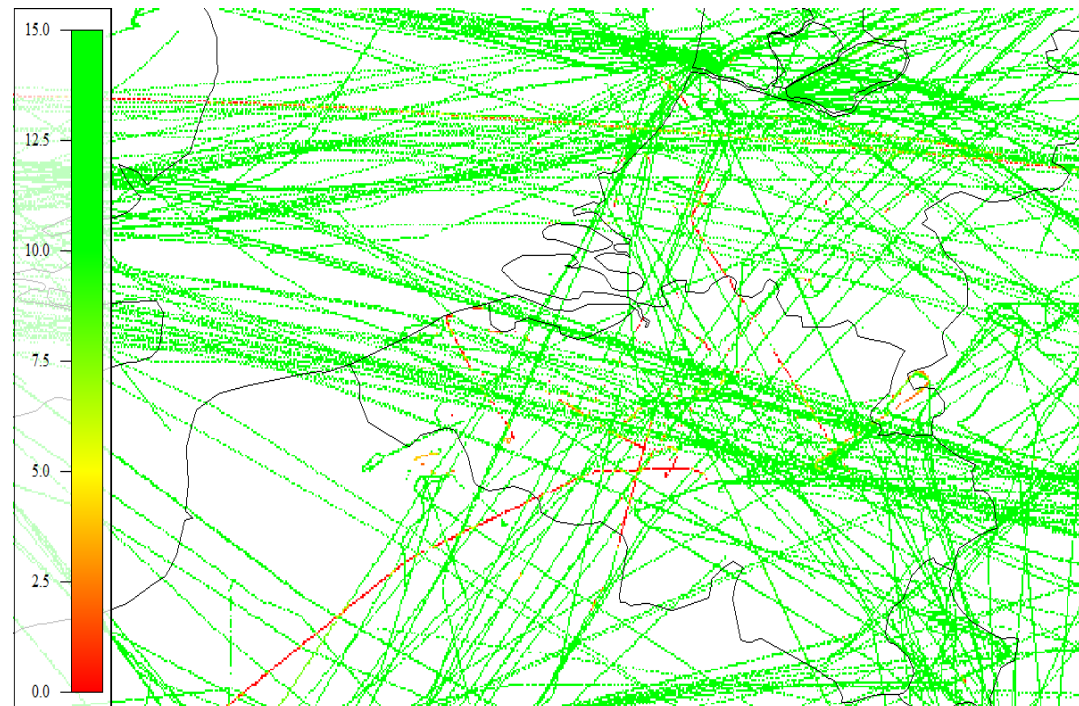
Jammer Antenna

RFI May Not Be Limited to Conflict Zones Only...

- End March 2021, 40W Anti-Paparazzi Drone Jammer on a Private Yacht
 - Jammer accidentally turned on by maintenance personnel, Southwest NL
 - Impacting air traffic in Netherlands, Belgium, France and MUAC for a few hours
- Core European airspace with climbing and descending traffic from some major airports
 - Info on affected flights **could be quite critical**, while large majority of flights **sees no impact**



ADS-B Gaps: 93 aircraft impacted,
Multiple aircraft per sector



ADS-B PIC, All Flights during event



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An exponential increase of GPS Spoofing Occurrence Reports since Dec. 2023

**Figure 4: GPS Spoofing Reports to CYANS per month
from 01/09/2023 - 31/12/2024**

(Source: DCAC CYANS Safety Management System Section)

First Proactive Alert by SMS

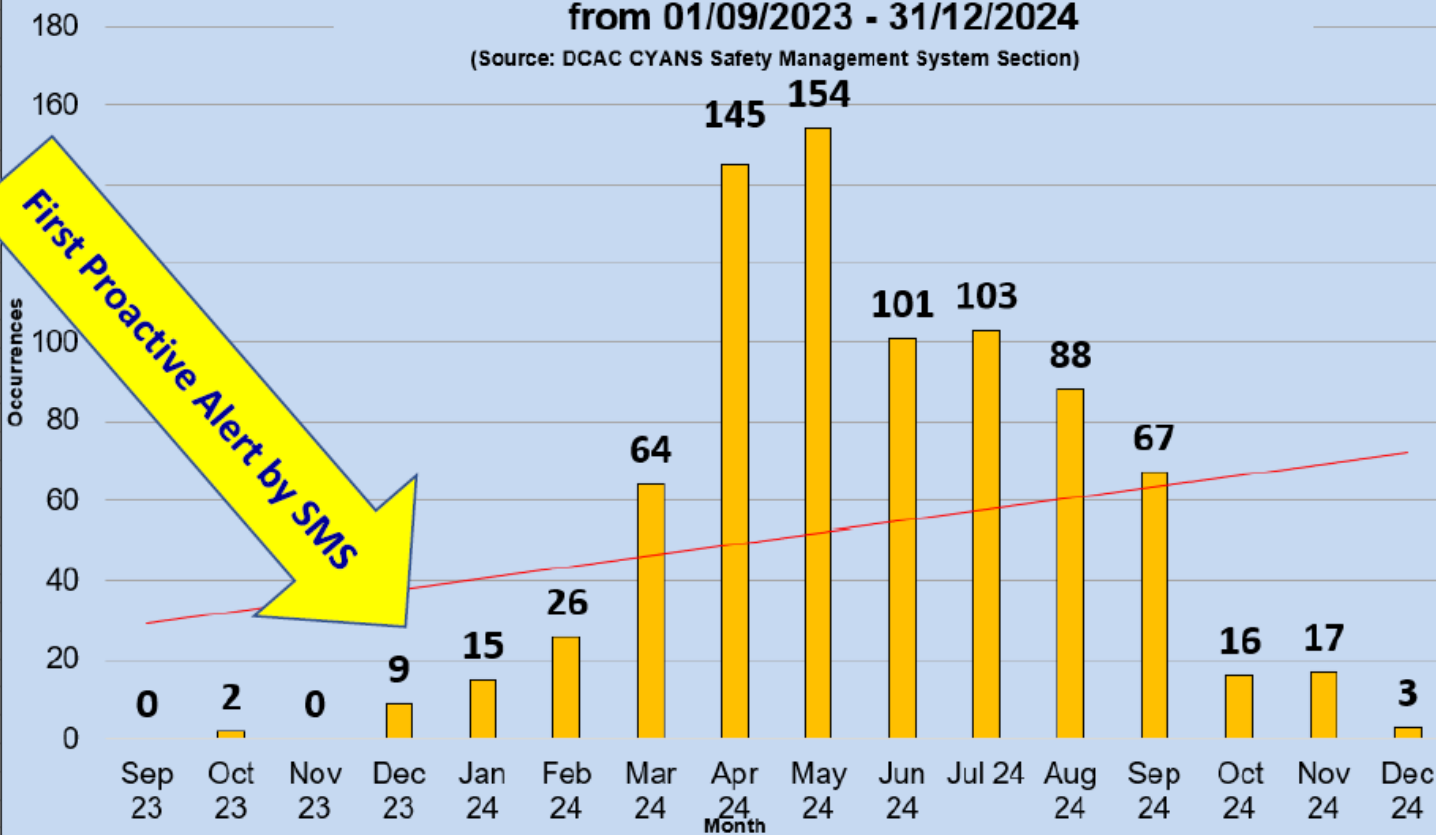
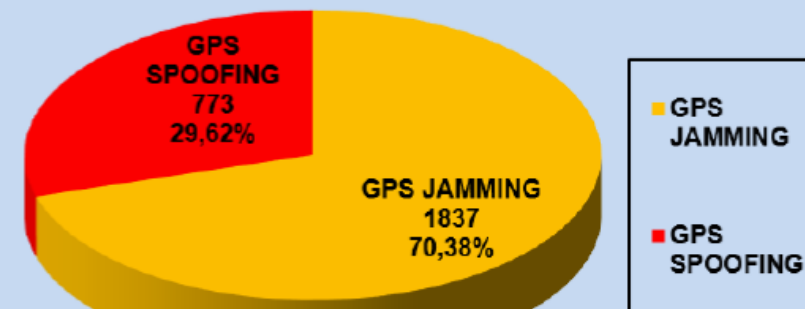


Figure 5: GPS Jamming vs GPS Spoofing occurrences for 2024

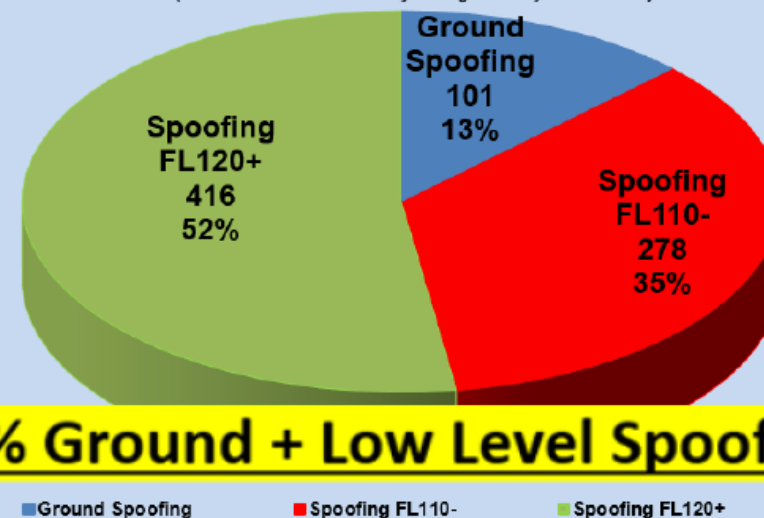


3:7 Spoofing to Jamming

Source: DCAC CYANS Safety Management System Section Jan. 2025

**Figure 6: 2024 Ground and Low Level GPS Spoofing up to
31/12/2024**

(Source DCAC CYANS Safety Management System Section)



48% Ground + Low Level Spoofing

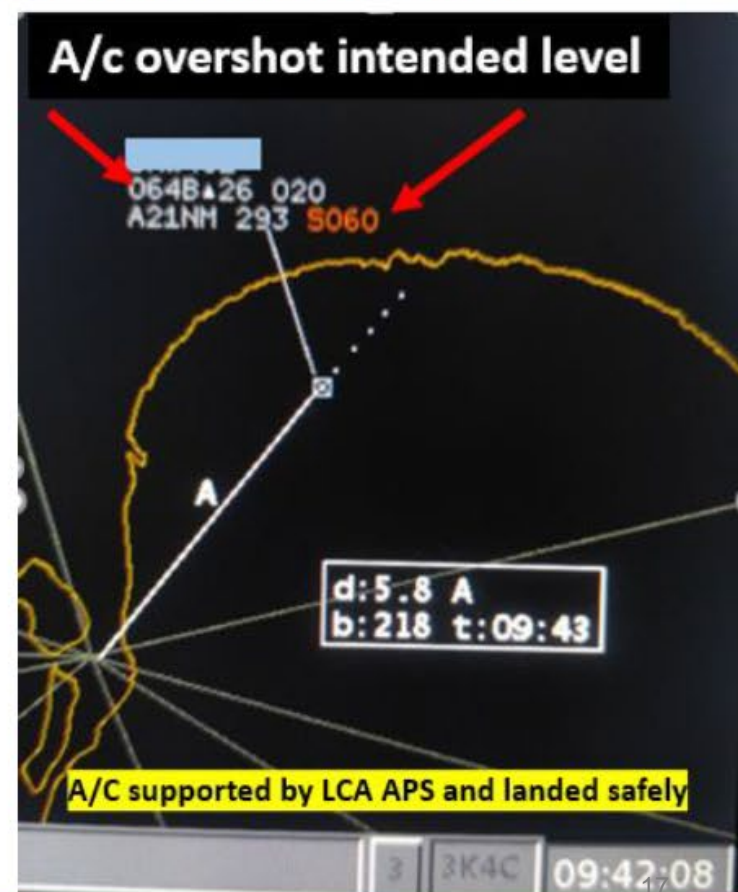
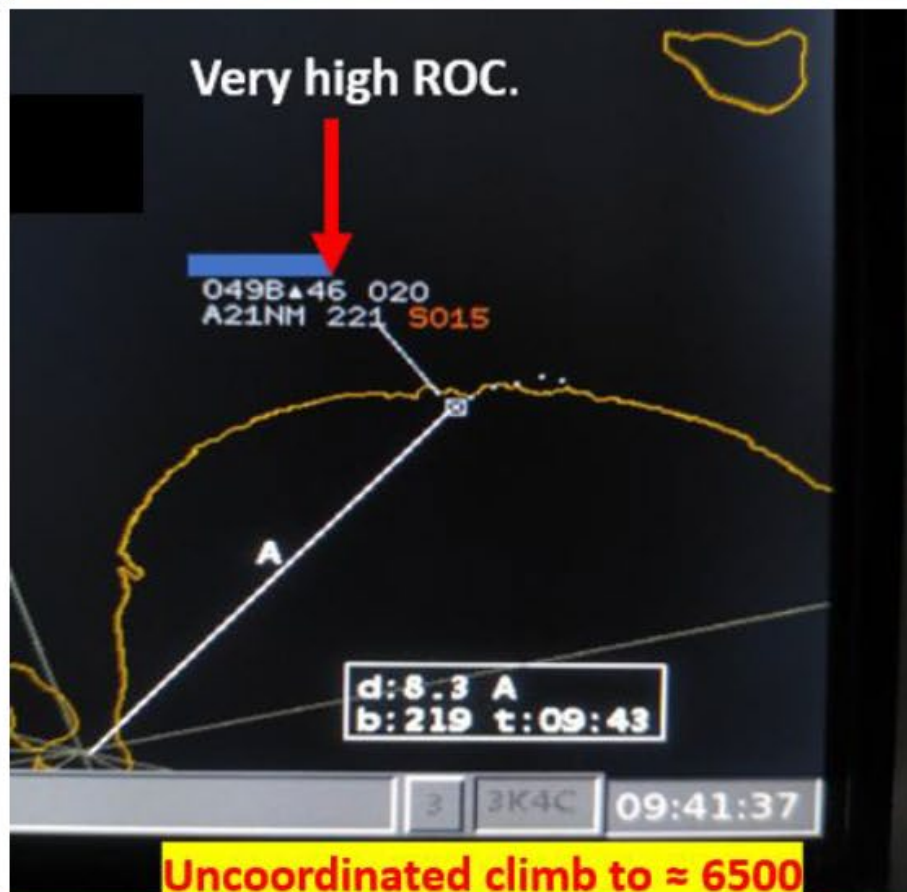


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Incident 1: April 2024, CAVOK, A321, under Larnaca TWR procedural control, at 1800 ft, turning to establish on ILS RWY 22, with clearance to land, reported “going-around”.

1. Initiated **Uncoordinated Climb** to ≈ 6500 due to reported GPWS alert, **Vertical Deviation from ATC Clearance**;
2. Without ATC clearance and without warning to ATC; Luckily no other traffic;
3. High rate of climb ($\approx 4600\text{ft/min}$);
4. Climbed to a different level than mode-s indication;
5. Overshot by 500ft the intended level.
6. A321 released to Larnaca Approach Surveillance Service (LCA APS), vectored to final and landed safely.





Incidents 6,7: Spoofing on departure, Lateral Deviation from ATC Clearance

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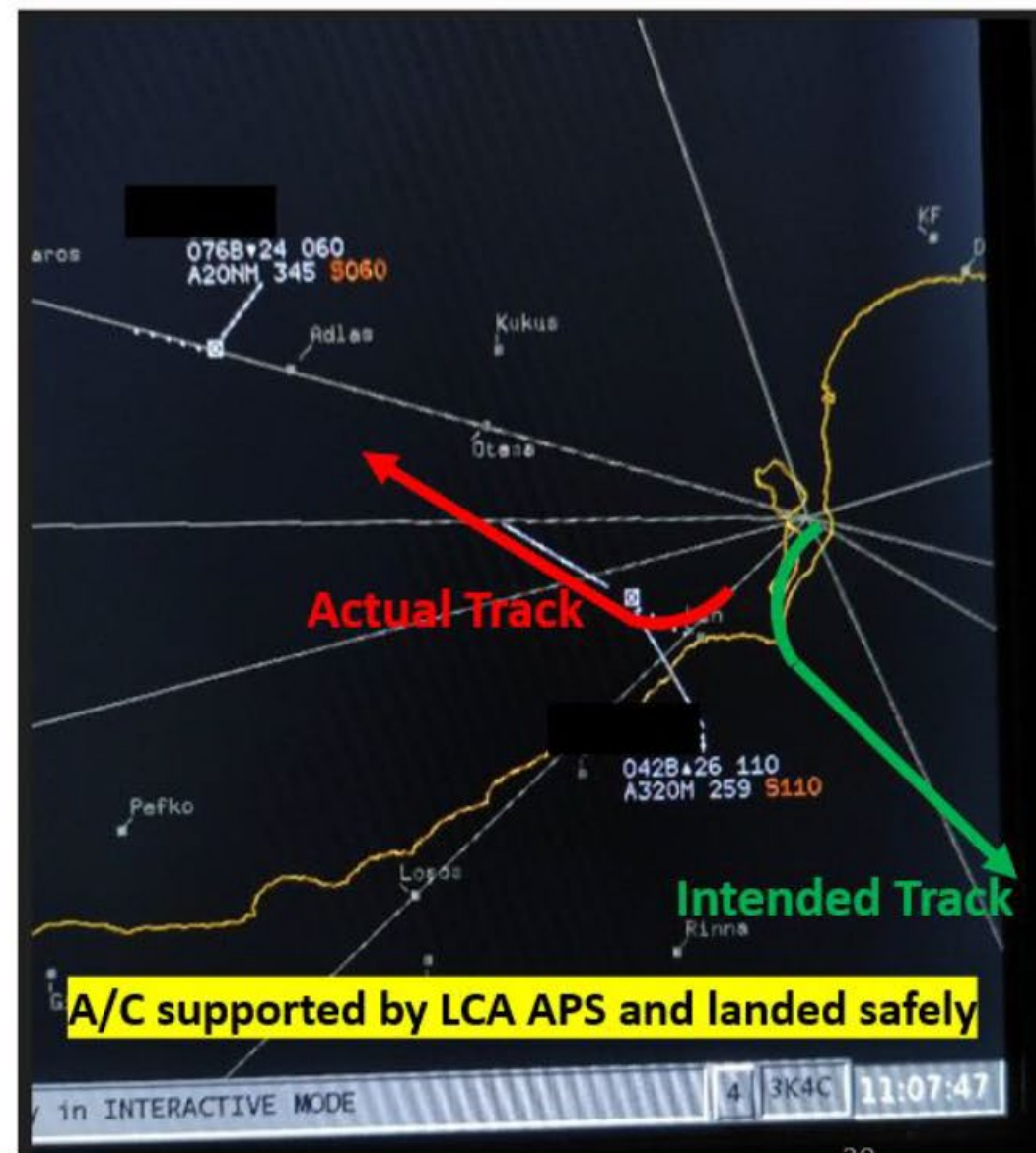
Incident 6:

1. April 2024, A320; After take-off Larnaca turned to the right instead of left
2. Daytime, CAVOK;
3. A/C reported GPS interference before departure and **requested conventional SID**;
4. **Clearance** for RWY 22 EMEDA 2B DEP **to the left over the sea**;
5. **After take-off, due to GPS Spoofing turned to the right towards DAROS, high terrain and opposite to inbound A320**
6. Conflict immediately resolved by APS (Approach Surveillance Service)

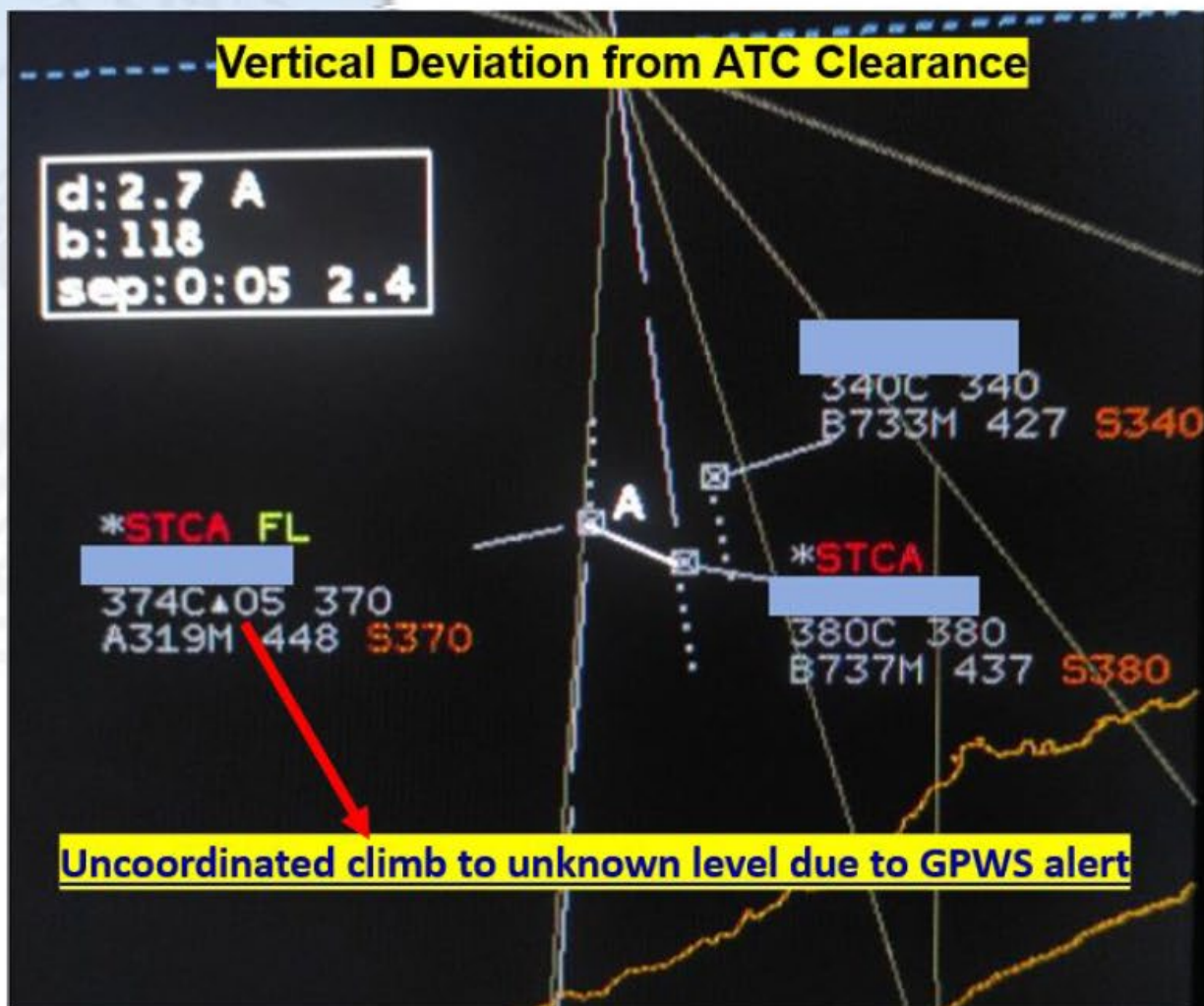
Lateral Deviation from ATC Clearance



Incident 6: April 2024, After departure, a/c reported unable to follow conventional departure, deviated to the west and provided navigational support



Incident 8: **Separation Minima Infringement (SMI)** in response to GPW at FL370



1. June 2024, 06:31 UTC
2. A319 over VESAR at FL370, Weather not relevant;
3. Responded to a GPW (due to GPS spoofing);
4. Commenced climb without ATC clearance;
5. Opposite direction traffic at FL380;
6. NACC ATC responded by providing essential traffic information to the a/c which climbed up to FL374, before descending back to FL370.

SUMMARY: GNSS RFI Impact

- Impact on all CNS elements: PBN, ADS-B, CPDLC
 - Plus large variety of cascading effects
 - Difficult to predict actual operational impact
- Most severe threat: Uncoordinated high-rate climb due to **false** Enhanced Ground Proximity Warnings (EGPWS / TAWS)
- Fundamentally undermines today's cockpit safety principles:
 - Trust your instruments
 - Follow Standard Operating Procedure (SOP)
- In some airspaces, operation in presence of compromised GNSS has become NORMAL OPERATIONS!
 - Extended Risk Exposure Time: Requires Independent CNS Elements to ALL WORK!
 - Collateral Impact at extended ranges from zones of conflict