GPSWISE

Navigating the future: Mitigating GPS Spoofing & Jamming Risks in Aviation

SKAI DATA SERVICES

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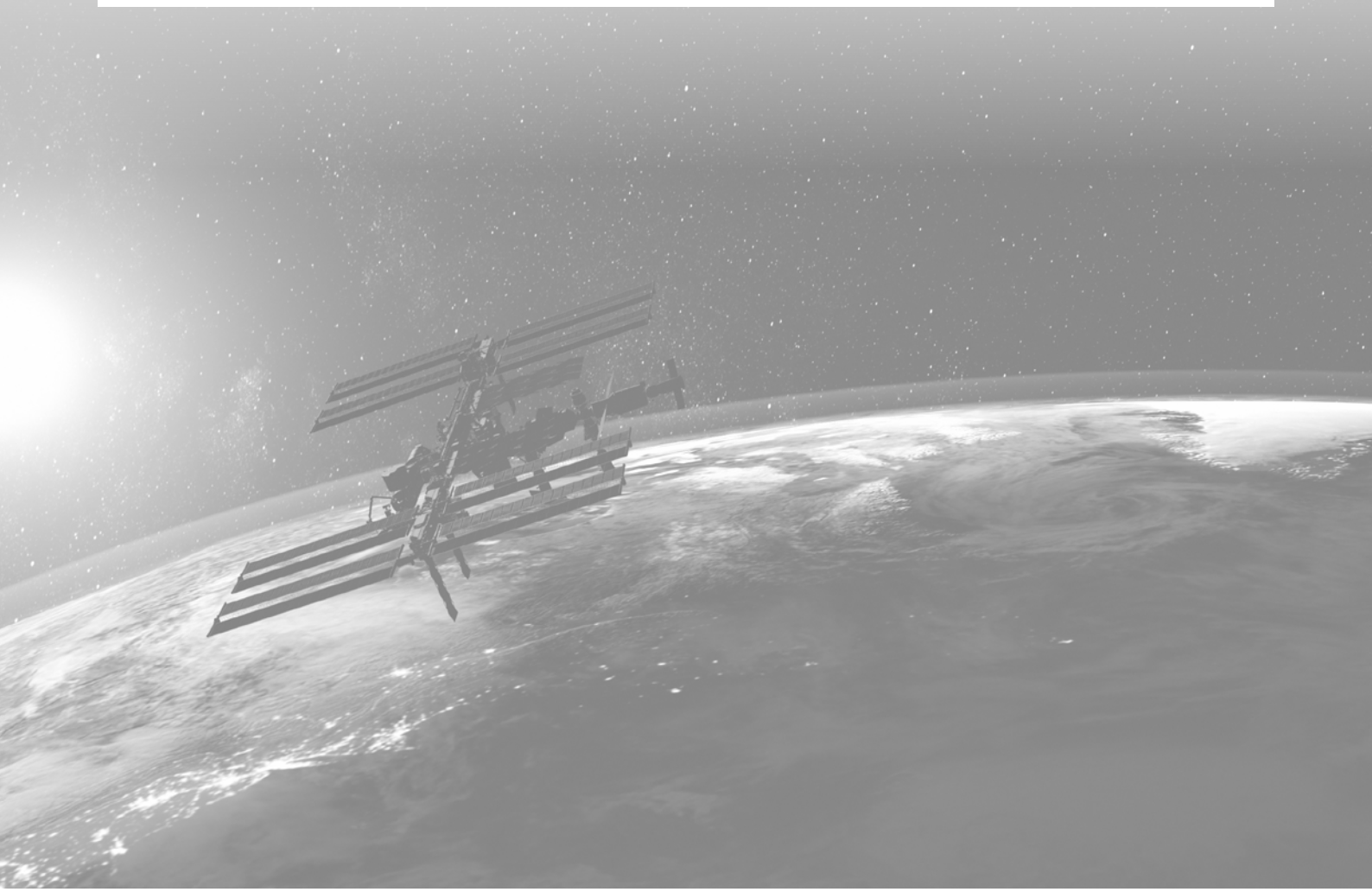
Executive Summary

Global Navigation Satellite Systems (GNSS), particularly GPS, are essential to modern aviation but are increasingly vulnerable to jamming and spoofing. These forms of interference have escalated in recent years, with GPS spoofing incidents reaching unprecedented levels in 2024, affecting hundreds of flights daily. The risks include aircraft deviating from flight paths, malfunctioning safety systems, and disruptions to essential navigation and communication capabilities.

SkAI Data Services has developed a product called GPSwise. This real-time GPS interference detection solution enhances situational awareness and flight safety. Using ADS-B data, GPSwise provides real-time alerts, interference mapping, and post-event analysis, enabling airlines, Air Navigation Service Providers, and other stakeholders to mitigate risks effectively.

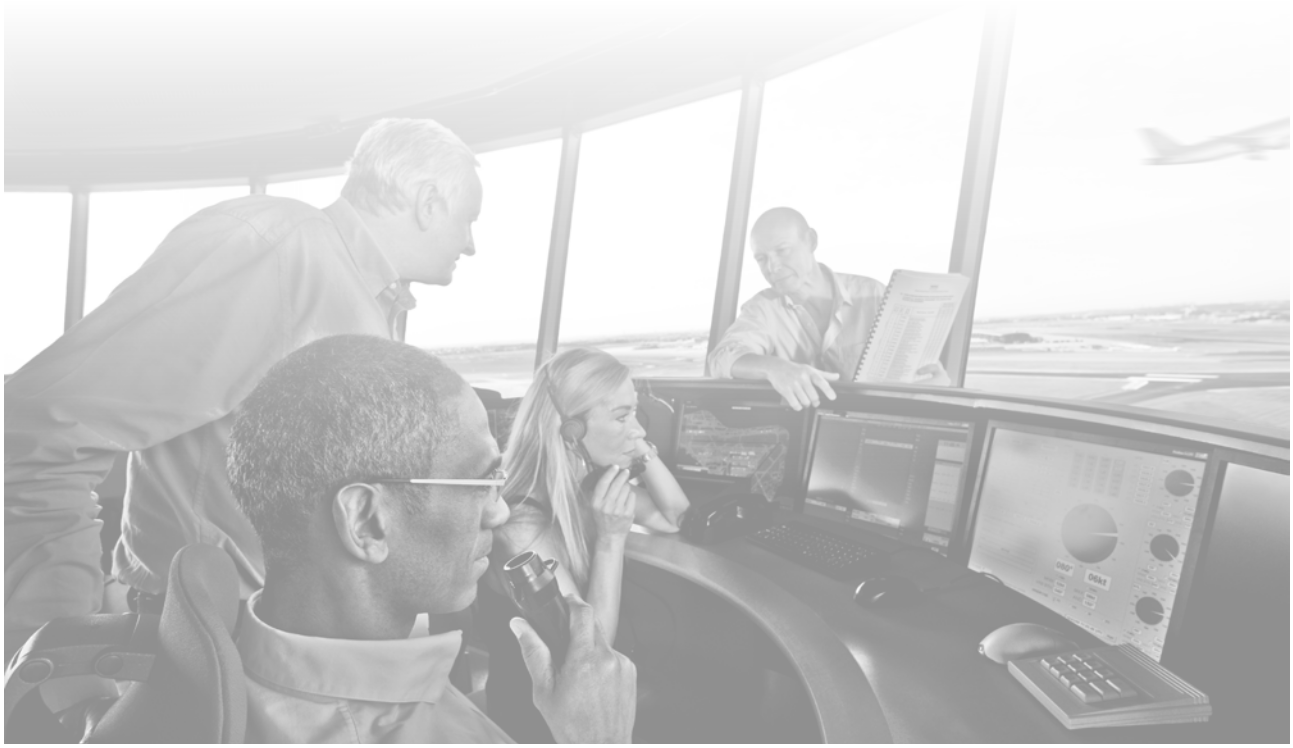
GPS interference is and remains unpredictable. Unfortunately, delays in the development and the potential high costs of implementing long-term technological countermeasures make them unavailable in the near and medium term. This paper outlines why real-time GPS interference detection is essential for aviation safety and how SkAI Data Services' GPSwise can provide an immediate and cost-effective solution.



Introduction

In the modern world, reliance on Global Navigation Satellite Systems (GNSS), particularly GPS, has significantly increased over the past decade due to its global coverage, high accuracy, and other indisputable advantages. Unfortunately, these systems are not without vulnerabilities, posing significant risks, particularly for aviation navigation. Due to the extremely weak GPS satellite signals, they are highly susceptible to interference, making aircraft casualties of jamming and spoofing. Emerging geopolitical tensions in recent years have exacerbated the problem, creating an urgent need for robust monitoring and mitigation solutions to ensure the integrity and safety of aviation systems. Recognizing this urgency, SkAI Data Services has developed GPSwise, a real-time GPS interference detection solution designed to enhance situational awareness and flight safety.

GPS interference is dynamic, widespread, and unpredictable, with impacts ranging from operational inefficiencies to safety risks. Air Navigation Service Providers and aircraft operators will benefit from GPSwise, our solution to monitor GPS interferences as they evolve in real-time.



Understanding GPS Interference

GPS satellites orbit Earth at about 20,200 km and send signals with a power between 50 and 240 W (comparable to a couple of light bulbs). As a result, the received signal is very weak. This opens the door for two primary types of interference: jamming and spoofing.

GPS jamming involves intentionally transmitting radio frequency signals to disrupt the reception of legitimate GPS signals. This causes the receiver to lose its lock on satellites and be unable to determine its position. Flight instruments can show this as 'no GPS position.'

GPS spoofing is a more advanced technique compared to jamming. It involves manipulating or overshadowing GPS signals to deceive an aircraft GPS receiver into calculating incorrect position, time, and altitude. The receiver now accepts the fake signal as genuine and relay the incorrect position to aircraft.

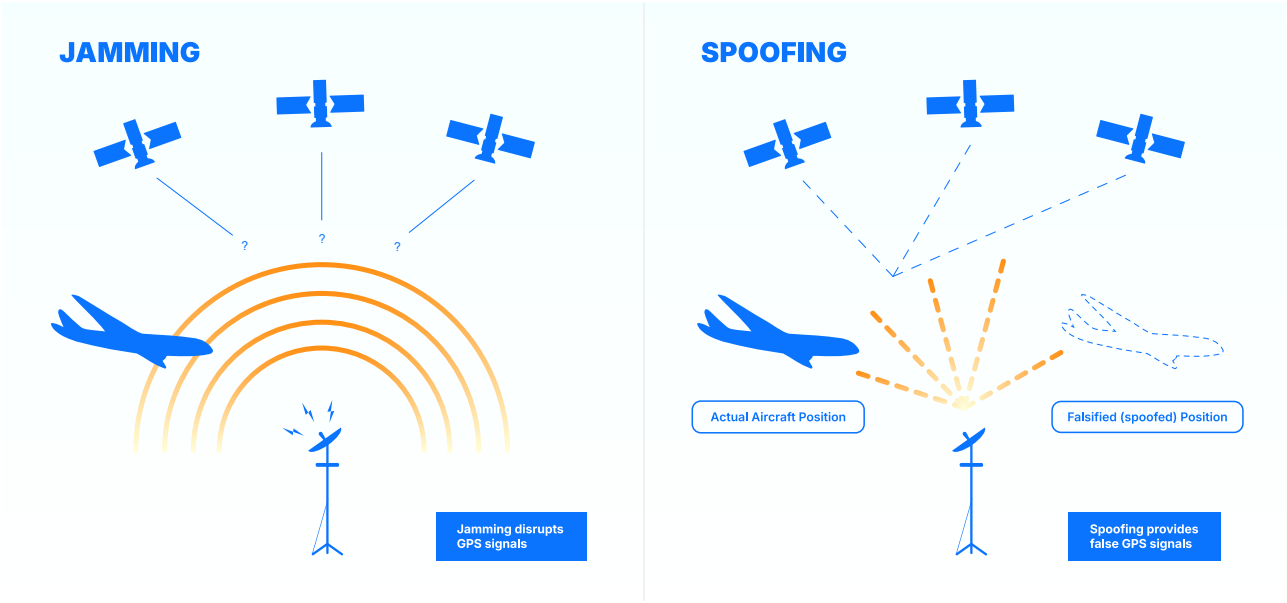


Figure 1. GPS reception during jamming and spoofing. Image source: OPSGROUP

The Worst-Case Scenario

The full gravity of the problem is best illustrated by the extent to which GPS interference can contribute to a catastrophe. On December 25, 2024, Azerbaijan Airlines flight J2-8243, operating from Baku to Grozny, encountered GPS interference and lost both GPS1 and GPS2. The crew requested vectoring and was cleared for a Non-Directional Beacon (NDB) approach. During communication with the tower, the crew expressed uncertainty about their altitude and position. Meanwhile, the Cockpit Voice Recorder (CVR) registered "PULL UP" warnings, and the Flight Data Recorder (FDR) indicated a time shift of 4 minutes and 32 seconds. After two go-arounds due to the low cloud ceiling, the crew decided to divert to Baku.

The loss of GPS navigation due to interference in the known conflict zone made the GPS approach unavailable, and foggy conditions reduced the chances of a successful NDB approach. The tragic events that followed, resulting in 38 lives lost, are attributed to atypical factors and are fortunately very rare. However, this radical example highlights the critical need for detecting areas of GPS interference, understanding associated risks, and developing robust strategies before the flight.

The Ministry of Transport of the Republic of Kazakhstan has published a Preliminary Report on the investigation into the crash. Based on its findings, the Preliminary Report contains the sole recommendation "to conduct a risk assessment for flights to regions experiencing reported Global Positioning System (GPS) signal loss".

Over 310,000 flights spoofed in 2024

GPS jamming and spoofing severely impact modern aircraft operations, which rely on accurate signals for navigation, communication, time, and situational awareness. GPS jamming has been prevalent for nearly two decades, while widespread GPS spoofing affecting aviation emerged in the autumn of 2023.

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Concerning increase in GPS Spoofing

In 2024 alone, SkAI identified over 310,000 flights affected by GPS spoofing. Spoofing events spiked globally, peaking around May 2024 with 1000 to 1500 flights affected daily. From July 15 to August 15, 2024, a total of 41,000 flights were spoofed.

Although the number of affected flights has subsided since May 2024, the overall situation is far from improving, with hundreds of flights affected daily at the time of writing.

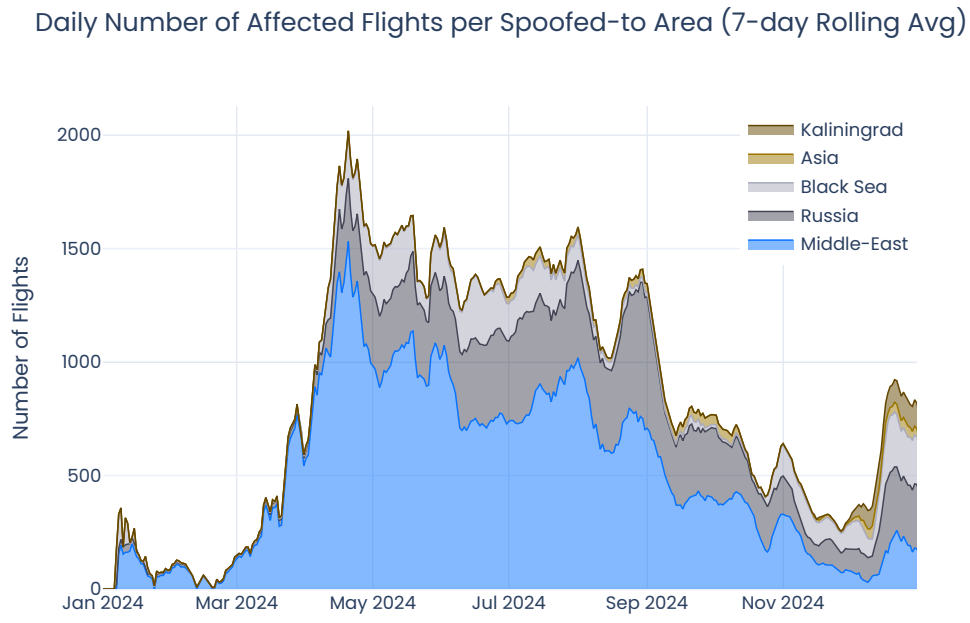

Figure 2. Number of detected unique flights per day. The colors indicate the geographical region.

Large-scale spoofing in conflict zones

The significant fluctuation in the number of flights affected by GPS interference is attributed to the operation of spoofers in high-traffic regions like the Middle East and the Black Sea. Both areas saw a change in spoofing patterns since the summer of 2024 and, subsequently, some reduction in their activities.

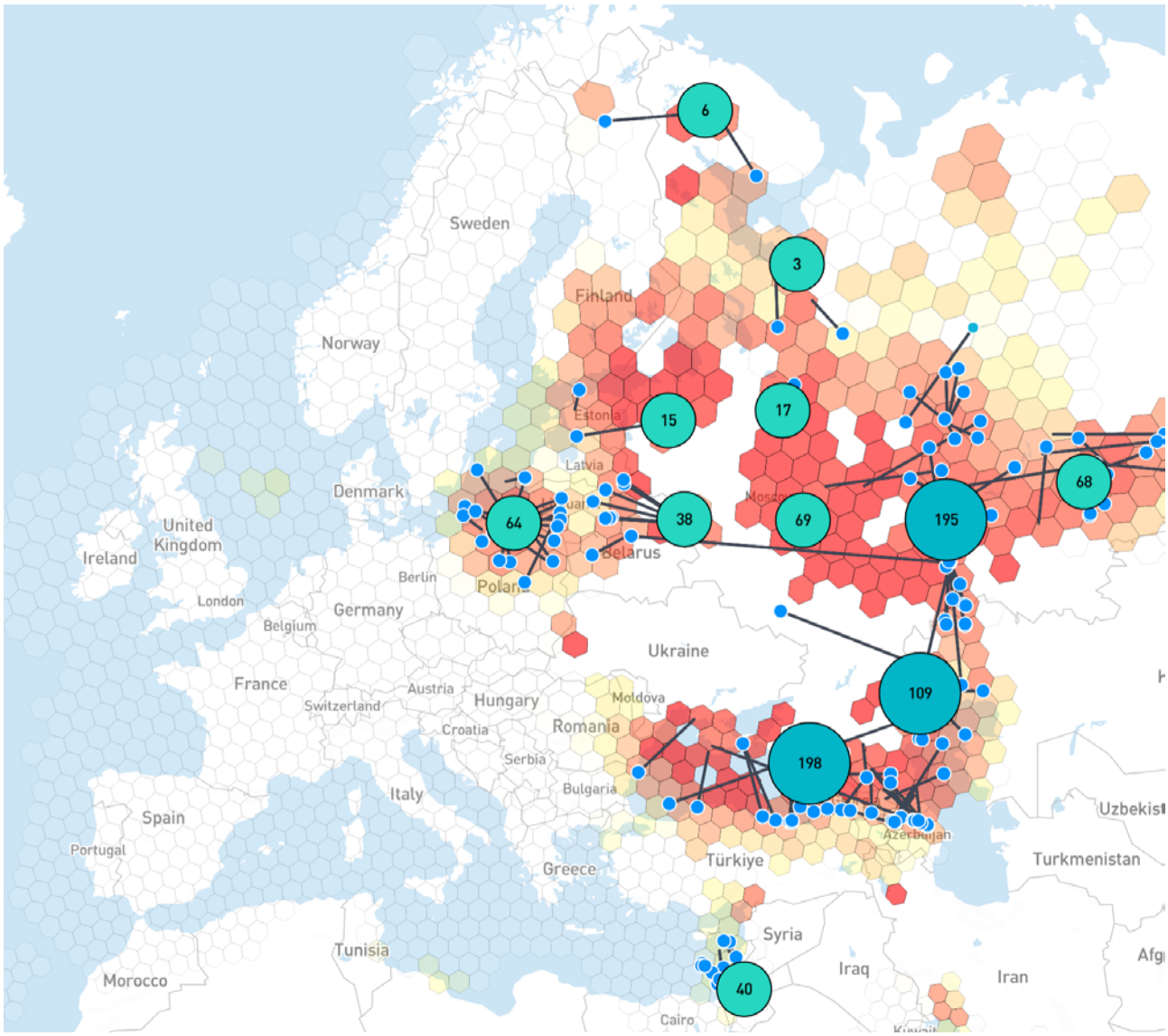

Figure 3. Spoofing and jamming in Europe. March 9, 2025

Unpredictable and Isolated Spoofing

Large-scale spoofers, like those in the Middle East and Russia, are well-known, allowing flight crews to prepare. However, smaller and less frequent spoofers also pose significant risks, as they can surprise flight crews and increase workload and the risk of loss of situational awareness.

Showcases: North Korea and Hong Kong

- **North Korea** GPS interference occurred on the southern border from May 28 to June 2, 2024, affecting even aircraft on the ground at Incheon International Airport.
- **Hong Kong and Macau**: Spoofing detected on December 18, 2024, coinciding with President Xi Jinping's visit, affecting aircraft in an area typically free from such interference.

Major concerns

According to the OPSGROUP Final Report published on September 6, 2024:

- The impact of GPS spoofing on flight safety, aircraft operation, and ATC operations is highly significant.
- 70% of nearly 2,000 flight crew rated their concern about GPS spoofing's impact on flight safety as "very high" or "extreme."

The following five issues caused by GPS interference illustrate the danger to air traffic.

1. Steering Off-Track

GNSS interference can cause an aircraft to deviate from its intended flight path, possibly entering restricted or dangerous airspace. This poses risks to safety and security and, in extreme cases, could result in airspace violations and military interventions. Deviations can also increase fuel consumption and delays, though significant deviations have rarely been reported.

Showcase: Baghdad airspace

- **Baghdad airspace:** An Embraer Legacy 650 flying from Europe to Dubai experienced GPS loss and IRS failure in Baghdad airspace. The autopilot started to turn erratically, revealing the issue. Following error messages on the FMS regarding GPS, radar vectors were requested. The aircraft was about 80 nm off track, nearly entering Iran airspace without clearance. *Source: OPSGROUP*

Figure 4. A spoofed aircraft almost entered the Tehran FIR without clearance. September 2023. Source OPSGROUP

2. Malfunctioning Enhanced Ground Proximity Warning System

One of the most significant safety concerns is the faulty functionality of the Ground Enhanced Ground Proximity Warning System (EGPWS) after GPS spoofing. GPS data determine the aircraft's position relative to the terrain. Erroneous "PULL UP" warnings cause potentially dangerous reactions from the flight crew, including uncoordinated climbs into higher flight levels. The dramatic increase of reported false alarms can lead to the normalization of risks and erode trust in these critical safety systems, risking delayed or no response in emergencies.

3. Reduced Navigation Performance Post-Interference

Even after leaving areas of direct GPS interference, some avionics systems struggle to recover without a restart, leading to operational challenges. This can prevent aircraft from meeting Required Navigation Performance (RNP) requirements and complicate aircraft separation and terminal navigation.

Showcases: Transatlantic and Morning air traffic over Europe

- **Transatlantic:** In the summer of 2024, we analyzed 397 transatlantic flights spoofed over the Black Sea. It revealed that 10% of these flights were still broadcasting drastically reduced navigation performance upon entering Oceanic airspace.

4. Unavailability of GPS Approaches

RNP approaches, along with other precision approaches that use GPS-based augmentation like GBAS (Ground-Based Augmentation System) and SBAS (Satellite-Based Augmentation System), all rely on GPS. When GPS is disrupted by interference, the corresponding approach procedures become unavailable. At some airports, no alternative precision approach is available.

Showcases: Dallas and Tartu

- Dallas: In October 2022, Dallas-Fort Worth International Airport (DFW) faced extensive GPS interference, leading to flight rerouting and a runway closure. During approach and landing, aircraft that experienced GPS loss used backup systems like the Instrument Landing System (ILS). The availability of such backup systems prevented further disruption.
- Tartu: On April 29, 2024, Tartu Airport in Estonia had to suspend its only international route to Finland due to GPS interference. The limitations of the ground-based systems at the airport prevented aircraft from safely approaching and landing.

5. Loss of Datalink

GPS spoofing can disrupt an aircraft's GPS time and internal clock, causing misalignment. This interferes with datalink communications like Controller-Pilot Data Link Communications (CPDLC), which depend on accurate time synchronization. Loss of CPDLC obstructs efficient communication between pilots and ATC, especially in oceanic and remote airspace. This increases workload and reliance on voice communications, leading to potential risks in high-traffic areas or during emergencies.

Our Detection Solutions

In spring 2024, SkAI Data Services launched the world's first near real-time GPS spoofing and jamming detection in collaboration with the Zurich University of Applied Sciences and the OpenSky Network. Our detection algorithms use Automatic Dependent Surveillance-Broadcast (ADS-B) data sent by aircraft and received by crowdsourced receivers around the world.

Since the launch, we have been refining the detection algorithms and developing professional services. In addition to the interactive map on https://spoofing.skai-data-services.com/, we provide tailored integrations into other products and services. Using a service like GPSwise enables you to anticipate and plan for GPS interference and increase flight safety and operational efficiency.

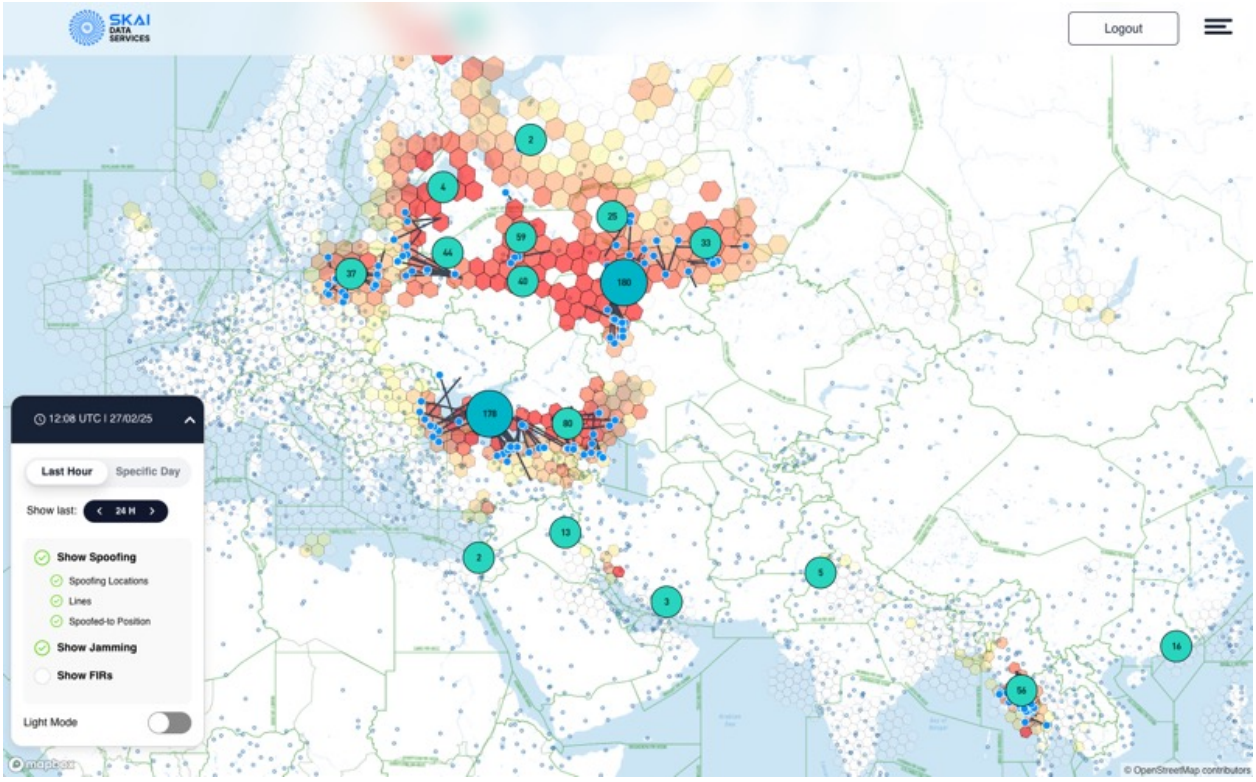

Figure 5. Screenshot of the GPSwise website.

Proactive Flight Planning:

Our data provides up-to-date interference zone mapping, similar to a weather map, allowing pilots and dispatchers to anticipate GPS disruptions. Unlike static FIR-based reports, our system continuously updates affected areas, ensuring that decisions are based on up-to-date information.

Real-Time Alerts:

When an aircraft encounters GPS interference, our system provides near real-time notifications. This enables crews to verify navigation system integrity, apply mitigation procedures, and maintain situational awareness. Dispatchers can assess the operational impact, support affected flights, and adjust future routing strategies as necessary. Additionally, such notifications can be used to trigger maintenance procedures for certain aircraft types or to generate incident reports.

Optimized Operations:

By continuously monitoring interference along key air routes, our data enhances operational decision-making. Airlines can proactively adapt flight paths, assess potential disruptions, and coordinate mitigation strategies with dispatch and ATC. This improves operational resilience and reduces the risk of unexpected navigation issues during flight.

Post-Event Analysis:

Detailed event records provide essential data for identifying trends, supporting maintenance investigations and ensuring regulatory compliance. By analysing interference patterns, operators can refine risk assessments, enhance procedural responses, and contribute to industry-wide safety improvements.

Advantages of ADS-B Based Detection

Monitoring GPS interference with ADS-B data offers comprehensive coverage and real-time insights that traditional ground-based monitoring networks alone cannot always provide. GPS ground monitoring stations offer deep insights into the signal quality and interference patterns. However, they are often sparsely distributed and have line-of-sight limitations. ADS-B data fills these gaps, delivering a more complete and timely view of interference and enabling faster, more informed decision-making at a reasonable price.

Tailored Solutions for Industry Stakeholders

For Airlines

Flight crews struggle with unexpected navigation disruptions that increase workload and safety risks. GPSwise can be integrated into your favorite Electronic Flight Bag or dispatch application. Having up-to-date information available for pre-flight briefings, combined with your operational procedures, increases situational awareness and flight safety. Additional services, such as alerting and report generation, can also be integrated.

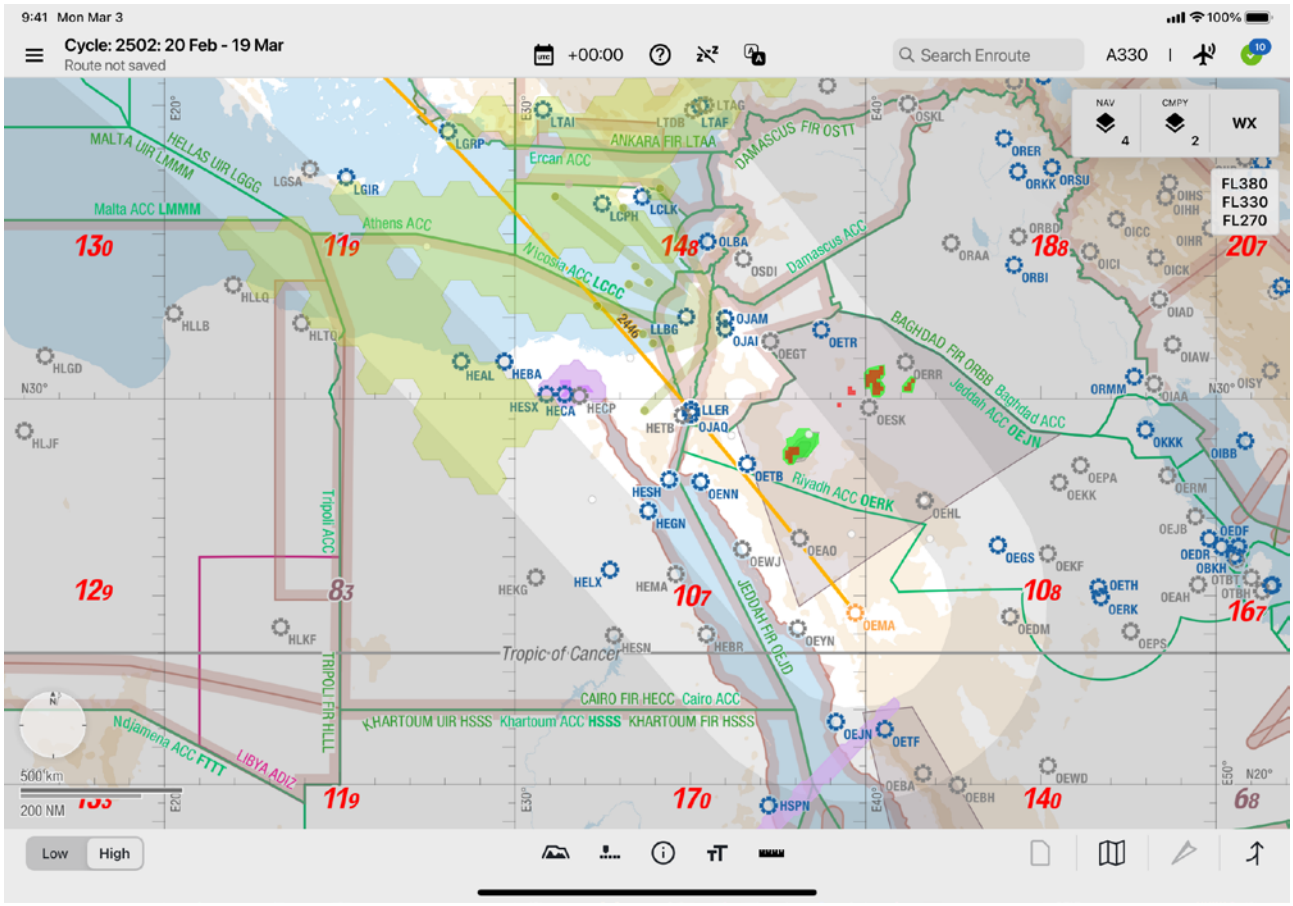

Figure 6. Integration of GPSwise Spoofing and Jamming layers in Lufthansa Systems' Lido mPilot.

> ***"At SmartLynx Airlines, we use GPSwise as a tool to enhance situational awareness of flight dispatch team and our pilots during pre-flight briefings about potential areas of GPS interference. This information is essential to pre-emptively apply our operational procedures and successfully mitigate some of the negative effects on the aircraft systems, contributing to safer and more efficient operation."***
>
> **Aleksejs Pozarskis,**
> Nominated Person Flight Operations SmartLynx Airlines Estonia OÜ

For Air Navigation Services Providers

Unmonitored GPS interference threatens airspace safety and disrupts air navigation services. GPSwise enables continuous monitoring of jamming and spoofing, allowing ANSPs to take proactive control measures. Our solution not only provides real-time alerts, but also identifies aircraft that are currently spoofed, those previously affected, and those with degraded navigation capabilities. We provide factual data to support incident investigations, enforce safety protocols, and improve navigation system resilience. If required, our detection algorithms can run on your ADS-B data and combine it with other surveillance sources, such as SSR or MLAT, to improve accuracy and robustness.

For Data Service Providers

Traditional aviation data lacks real-time GPS interference insights, limiting its value. GPSwise provides valuable information that can be aggregated and integrated into third-party data products. In many industries, such as insurance, intelligence, or defence, augmenting existing data products with GPS interference can add additional value to the customer.

For Regulators

A lack of real-time GPS interference data makes enforcing safety regulations challenging. GPSwise provides regulators with live monitoring capabilities to ensure compliance, prevent hazardous flight conditions, and reduce the dependency on filed reports. Our data delivers data-driven insights, helping regulators shape more informed and proactive safety policies.

For Insurance Companies and Aircraft Lessors

Understanding the exposure to risks from GPS interference can be difficult for insurance companies and aircraft lessors. GPSwise can help by providing the necessary data to quantify these risks. For example, identifying the number of spoofed aircraft of an operator can inform the negotiation on requirements for GPS interference mitigations and procedures. This ensures that operators manage their risks proactively.

Outlook

The aviation industry has recognized the urgent need to mitigate the negative impact of GPS interference on flight safety. Existing countermeasures, such as cryptographic authentication, multi-constellation GNSS usage, and data fusion with inertial systems, look promising. Unfortunately, widespread adoption of these countermeasures is challenging due to technical, operational, and regulatory constraints. Therefore, they may only be operationally available in a few years.

Until such mitigations become available, we are happy to support you with GPSwise. We are committed to continuously maintaining and optimizing our detection algorithms to stay on top of the constantly changing interference patterns and technologies.

Conclusion

GPS interference, especially spoofing, poses a growing threat to aviation safety and efficiency, and the recent events highlight the urgent need for detection and mitigation. GPSwise provides a proactive solution, offering real-time monitoring to enhance situational awareness. While long-term countermeasures are in development, immediate action through detection and data-driven decision-making is essential to maintaining safe and reliable air operations.

Visit **https://spoofing.skai-data-services.com/** to see real-time GPS interference data in action,

or contact us at **contact@skai-data-services.com** to schedule a demo.

About SkAI Data Services

SkAI Data Services is a spin-off from the Zurich University of Applied Sciences (ZHAW) and provides data-driven services for the aviation industry. The authors of this paper, Benoit Figuet and Raphael Monstein, are the co-founders and research associates at ZHAW. They were awarded a fellowship at the Cyber Defence Campus of the Swiss Federal Office for Defence Procurement (Armasuisse) for their work on GPS interference detection.

Sources

- *For a detailed description of the operational issues with GPS interference, the excellent report by the OPSGROUP is highly recommended and can be found at https://ops.group/blog/gps-spoofing-final-report.*
- *Unfortunately, most of the preliminary report on the crash of Azerbaijan Airlines flight J2-8243 is in Russian, but some of the radio communication is in English. https://www.gov.kz/uploads/2025/2/4/84f9ee83af415a658fc3d2830d317889_original.3875924.pdf*

Acknowledgement

We want to thank Daria Senchenia for translating the relevant parts of the preliminary investigation report and Dr. Michael Felux for inspiring our initial investigation into GPS interference detection and for his ongoing support.