ICAO

INTERNATIONAL CIVIL AVIATION ORGANIZATION

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GNSS RFI
A Manufacturers' Perspective

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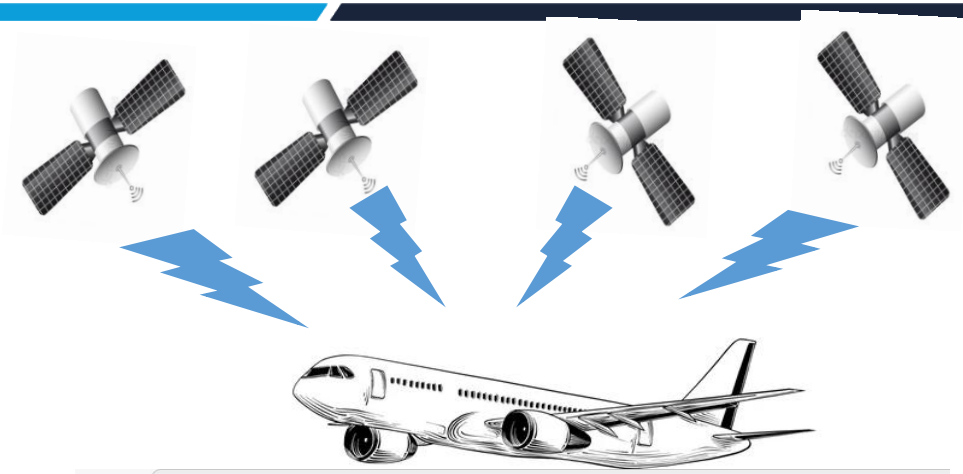
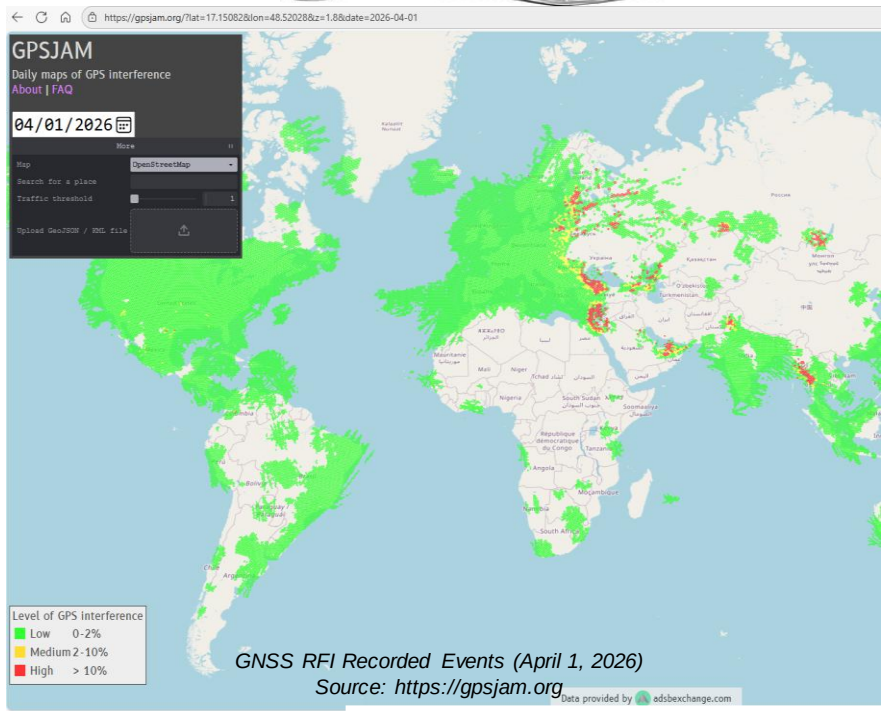
Boeing

GNSS RFI Overview

- GNSS RFI refers to any unwanted radio signal that interferes with the reception satellite signals, potentially degrading or preventing accurate positioning, navigation, and timing.
- Unintentional interference can result from unregulated radio transmitters that transmit on radio frequencies protected for aviation. It can also be caused by rare atmospheric electromagnetic events or malfunctioning radio frequency transmitters.
- Intentional interference can be due to:
  - Geo-political conflict by military, governments, etc.
  - Jamming, prevents/blocks the GPS receivers from receiving satellite signals and makes the system degraded or inoperative in the jammed area.
  - Spoofing, is a false satellite signal is sent to receivers causing incorrect position, altitude, and time data.

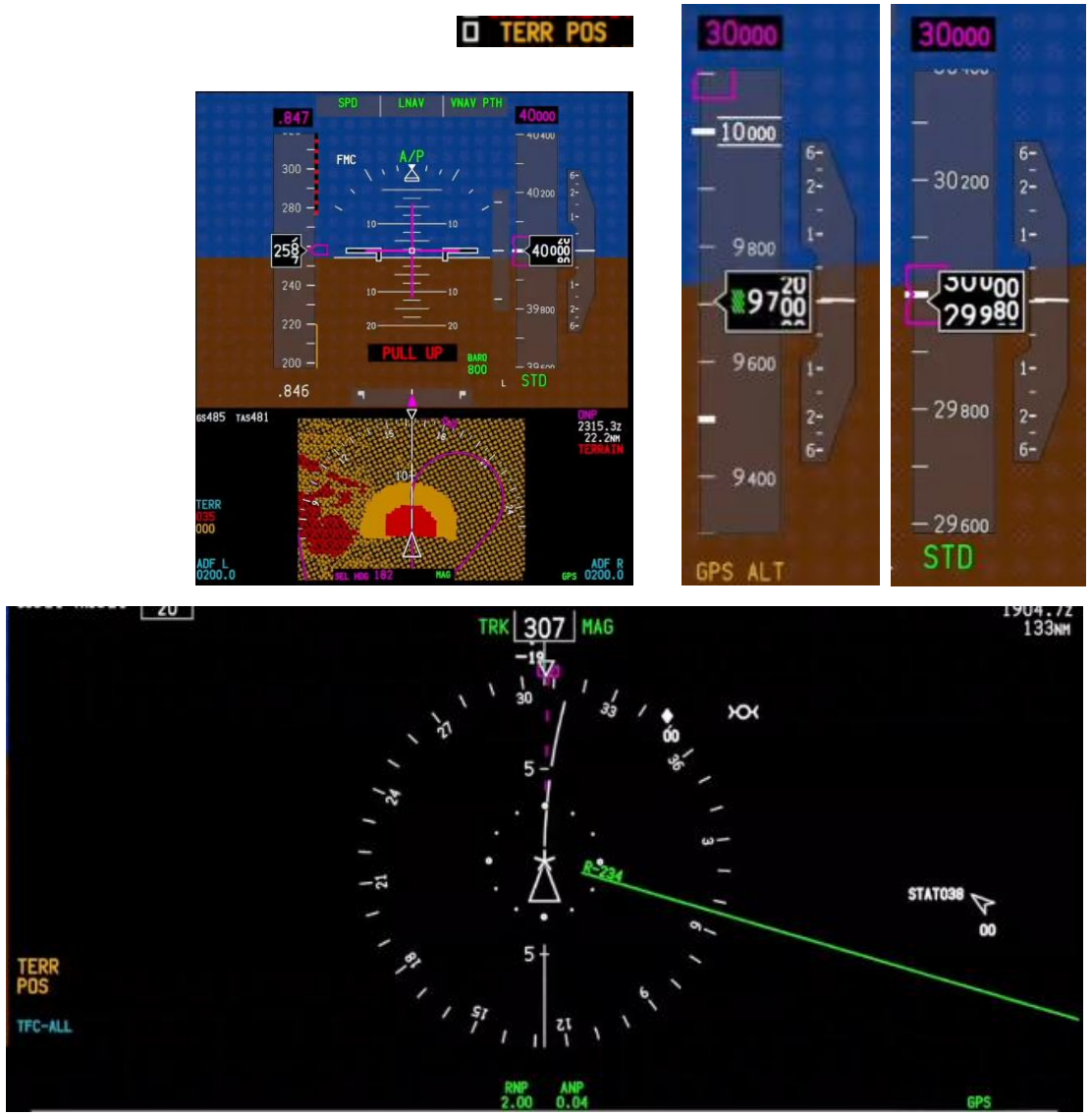




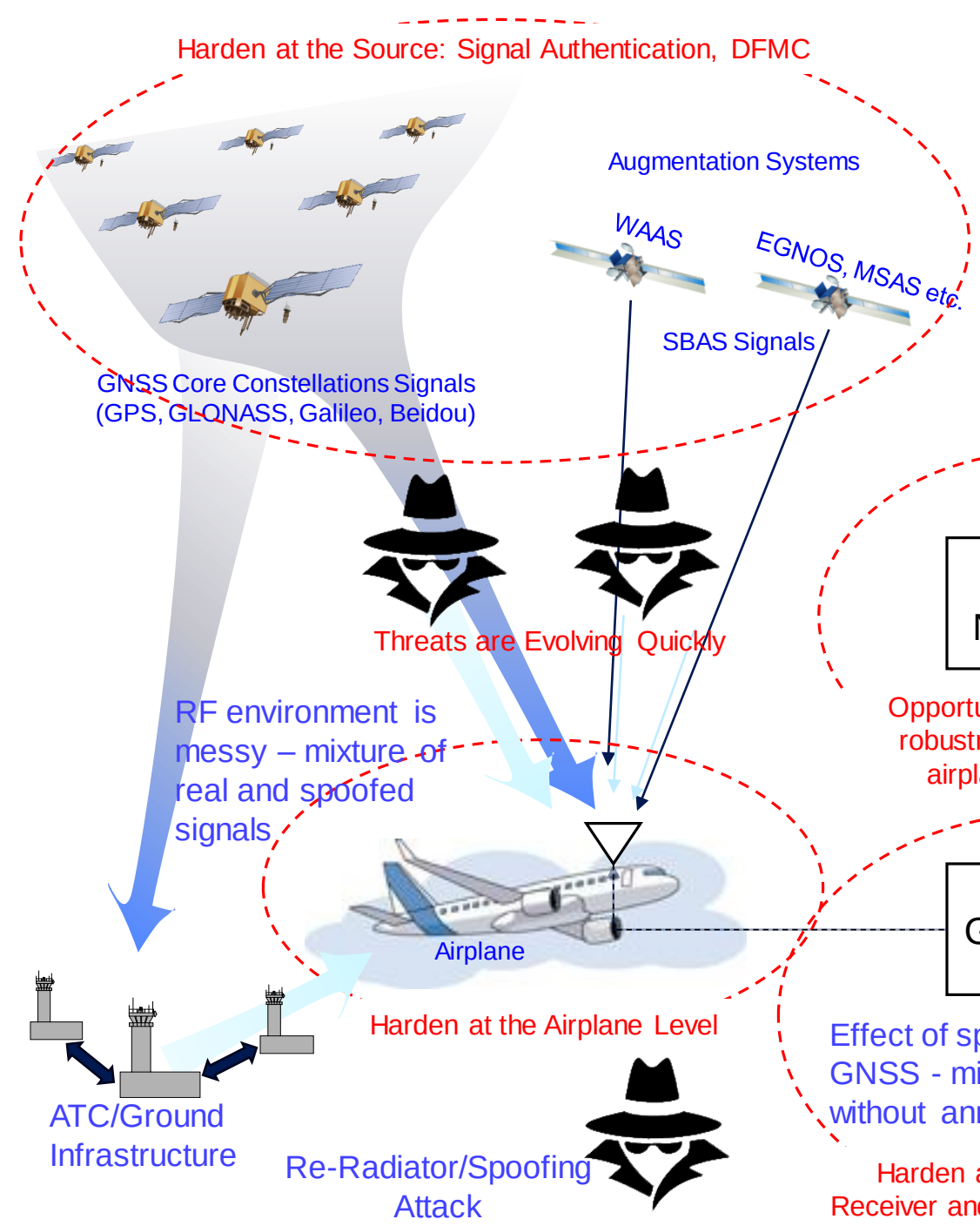
GNSS RFI Recorded Events (April 1, 2026)
Source: https://gpsjam.org

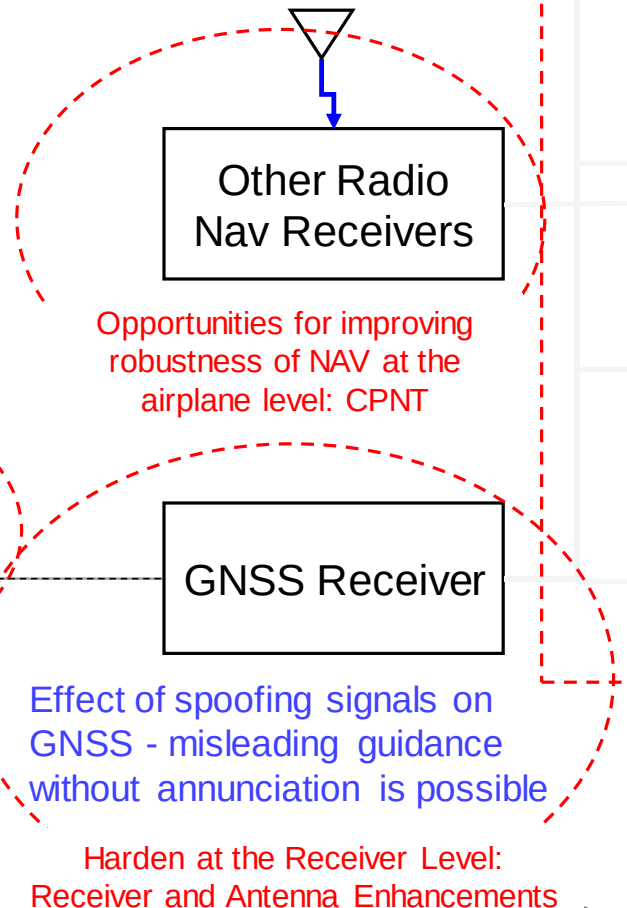
Observed GPS System Effects

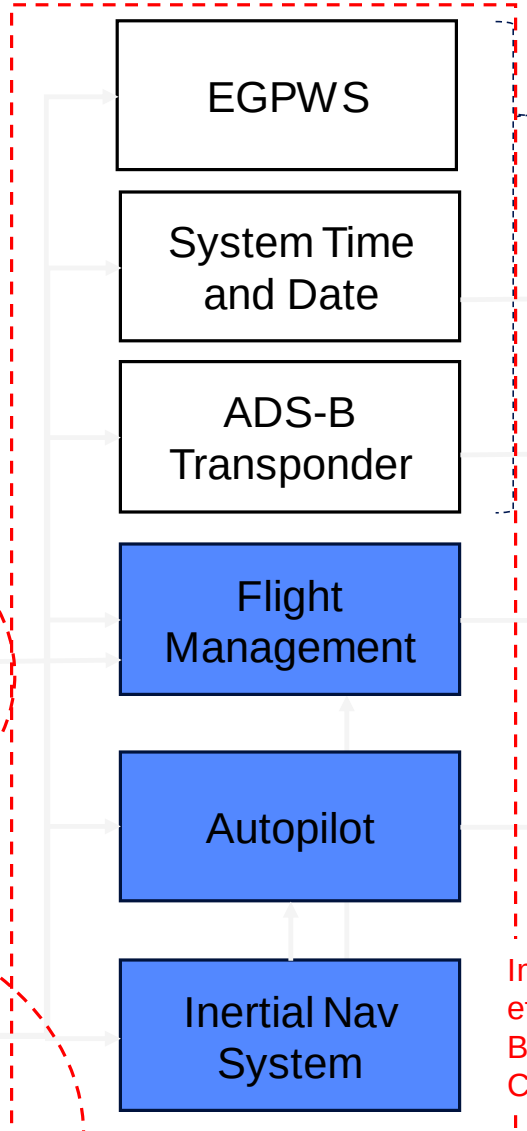
- Erroneous position
- Erroneous HUD Guidance
- Abnormal differences between Ground speed and True airspeed
- Time / Date shift
- Spurious EGPWS alerts
- Loss of ADS-B
- Loss of Autopilot / flight director approach capability (NO LAND 3)
- Erroneous Weather Display
- Controller Pilot Data Link Communications (CPDLC) messages invalid or missing
- SATCOM logon invalid



787 Displays of GNSS RFI (simulated)







Some systems do less crosschecking and limited or no validation of GNSS information

Used without crosschecking by many airplane functions like Dataload and Datalink

Used by outside world for surveillance

Displays

Potential cockpit effects are numerous and depend on specific spoofing scenarios

Improve integration to make residual effects low impact
Better Multi-Sensor Nav Integrations
CPNT

These systems (in blue) do some level of anomaly detection via cross checking with other sensors. Designed for signal failures. Effectiveness unquantified for spoofing.

ICAO Actions - Long history of ICAO actions relative to GNSS RFI

- 11th Air Navigation Conference (ANCONF/11) (2003) – Recommendation 6/2 – Guidelines on mitigation of GNSS vulnerabilities
- Electronic Bulletin on Interference to GNSS Signals (eb 2011/56) (2011)
- 12TH Air Navigation Conference (ANCONF/12) (2012) = Recommendation 6/8 – Planning for mitigation of global navigation satellite system vulnerabilities
- Memorandum of cooperation with the international telecommunication union (ITU) (2012)
- ICAO NSP liaison statements to RTCA and EUROCAE on increased protection of GNSS receivers (2014)
- GNSS Manual (DOC 9849), 3rd edition (2017) and 4th edition (2023)
- 40TH Session of the assembly (2019) / State Letter 2020/89 (2020) / ITU Circular Letter 488 (2022)
- 41st session of the assembly (2022) / Assembly Resolution 41-8, Appendix C
- Amendment 93 TO Annex 10, Volume I (2023) – (Adds DFMC GNSS)
- 42nd session of the assembly (2024) / Assembly Resolution 42-1, 42-3 and 42-8
- Ongoing NSP work – Several job cards:
  - (NSP.009.03 (APNT) – Alternative Position Navigation and Timing
  - NSP.008.02 (RON) – Resilient Operational Networks
  - NSP.006.02 (RFI Mitigation) – GNSS RFI as well as L-band spectrum compatibility studies (LDACS, LEO sats etc.)

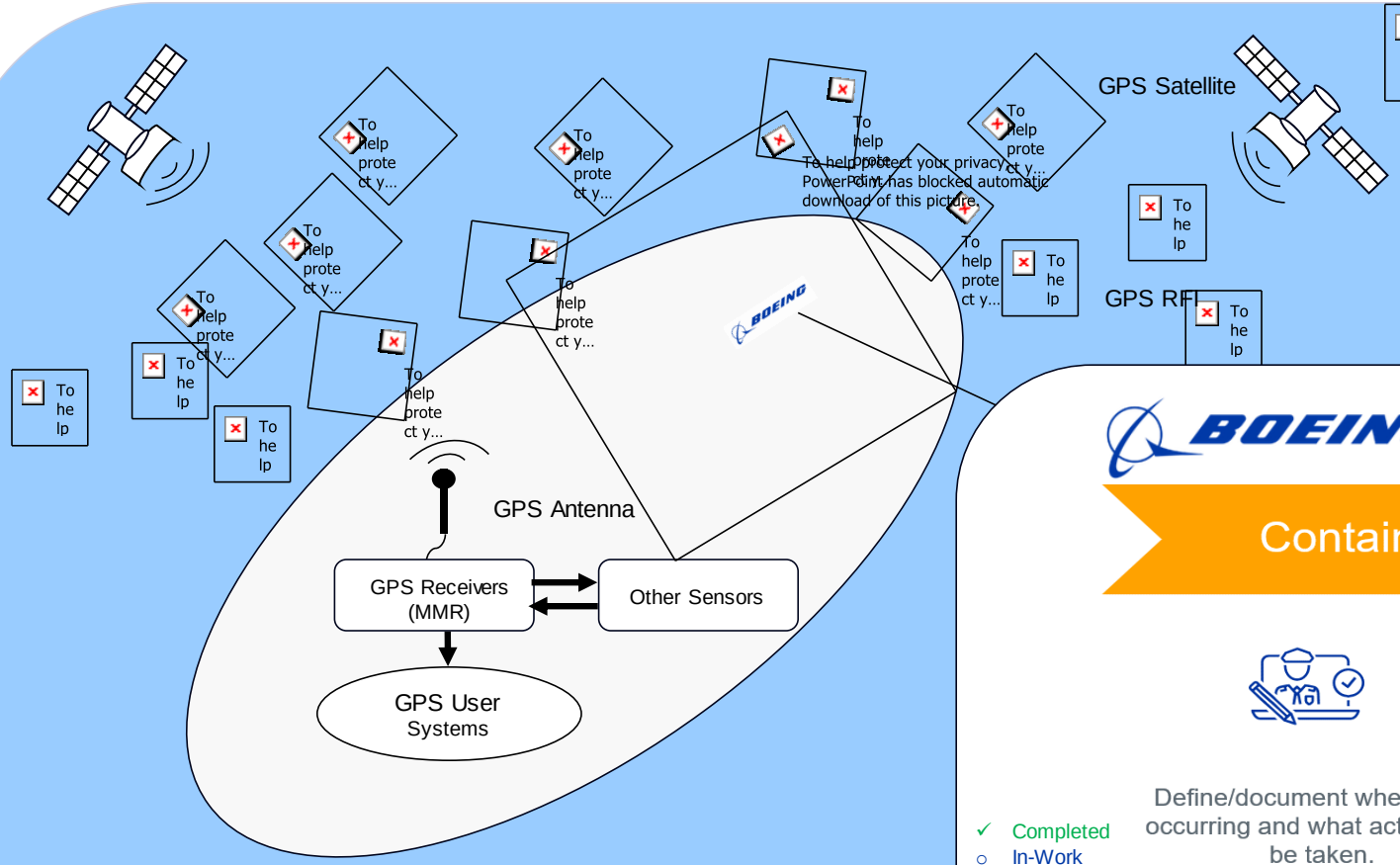
Other Industry Activities of Note

- **EUROCONTROL GNSS RFI Action Plan Task Force—**
  - Jointly spearheaded alongside the European Union Aviation Safety Agency (EASA), IATA, and ICAO
  - Established to mitigate the severe escalation of satellite navigation jamming and spoofing, particularly near geopolitical conflict zones.
  - Codified its objectives into the landmark **European Aviation Action Plan for Ensuring Safe Operations during GNSS Interferences**
  - The core pillars and milestones of the Task Force's work include:
    - Unified Operational Picture & Reporting
      - **SHERLOCK Platform & Data Fusing:** The task force relies heavily on EUROCONTROL's SHERLOCK data network. It tracks 1090 MHz ADS-B data from aircraft to identify hidden anomalies, mapping exactly what percentage of commercial flights are actively losing satellite signals per Flight Information Region (FIR)
    - Immediate Safety & Cockpit Interventions
      - **EGPWS/TAWS Mitigation**: The task force identified that the most severe, high-risk threat in the cockpit is collateral spoofing, which can trick aircraft computers into triggering false Enhanced Ground Proximity Warning System (EGPWS) hard-climb alerts. The task force worked directly with manufacturers to expedite software updates and training fixes to ensure pilots do not perform dangerous, uncoordinated maneuvers in busy radar airspace
      - **Harmonized Air Traffic Control (ATC) Phraseology**: Working within the ATM Procedures Development Sub-Group (APDSG), the task force developed standardized phraseology updates for ICAO PANS-ATM (Doc 4444).
    - Medium & Long-Term Infrastructure Resiliency
      - **Terrestrial Reversion Maps**: To support aircraft using multi-sensor navigation, the task force published the European GNSS Contingency/Reversion Handbook.
      - **Advanced Avionics Roadmaps**: The task force outlines a definitive transition path toward Dual-Frequency Multi-Constellation (DFMC) GNSS receivers and localized signal authentication protocols (such as Galileo's OS-NMA)

More Industry Activities of Note

- **RTCA SC-159/EUROCAE WG-62 MOPS development**
  - Focused on introduction of DFMC for SBAS and ARAIM
  - Developing new MOPS for DFMC
  - Baseline Framework Established (ED-259A / DO-401): Published in September 2023, no TSO planned
  - Validation Version (ED-259B / DO-401A): - designed to be the first certifiable standard for DFMC (FRAC in December 2026 expected to be published in early 2027).
    - Includes Horizontal Advanced Receiver Autonomous Integrity Monitoring (H-ARAIM)
    - Galileo Open Service Navigation Message Authentication (OSNMA)
- **RTCA SC-159-SG7/EUROCAE WG-133 – Standards for Controlled Reception Pattern Antennas**
  - Joint work just beginning – WG's have aligned TOR's etc.
  - Focused initially on a near term L1 only retrofittable Controlled Reception Pattern Antenna (CRPA)
  - Major issue is how to protect integrity when CRPA is active
- **RTCA SC-242 & EUROCAE WG-134: airborne interrogators.**
  - Jointly developing the Minimum Operational Performance Standards (MOPS) for airborne interrogators
  - Two phases:
    - Near term MOPS development intended to "harvest" current DME generation performance and enable DME/DME (or Multi-DME) to support RNP 0.3 operations
    - Longer term focus on next generation DME MOPS intended for future generation of DME interrogators

Boeing GNSS RFI Strategy



(Global Industry Cooperation) *External Factors*

- GNSS Frequency Protection (ICAO Doc 9849)
- Industry Standards & Technology Roadmaps
  - DFMC GNSS
  - GNSS signal authentication
  - Alternative Navigation Solutions
- Military-Commercial Trade Regulations (ITAR, etc.)

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Contain | **Improve** | **Resilient**

✓ Completed
○ In-Work

Contain

Define/document when RFI is occurring and what actions can be taken.

- ✓ Launched GPS RFI Task Force
- ✓ Monthly GPS RFI All Operator Calls
- ✓ Developed FOTBs for all major models
- ✓ Updated AMM/FIM Tasks
- ✓ Released MTs
- ✓ Released NNC & Updating SPs
- ○ Regularly updating FOTBs based on the latest reports
- ○ Safety investigations: PCOSP, PSRB, SMS
- ○ GPS Event Monitor (GEM) ACMF Live Report

Improve

Airplane system resilience improvements

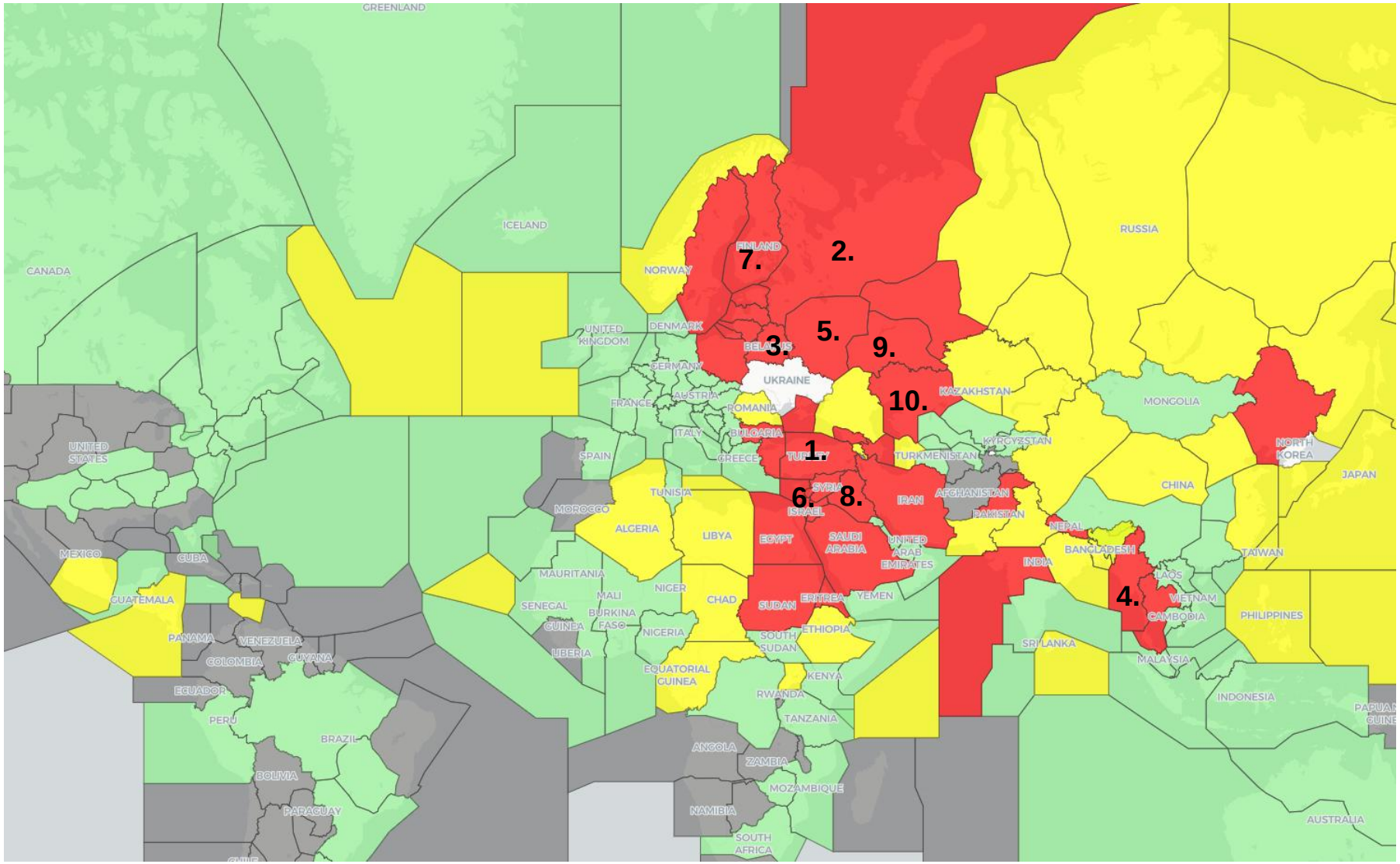
- ○ Updates for GNSS Receivers
  - ○ GLU2100 Phase 2.6
  - ○ GLU2100 Phase 3
- ○ Updates for EGPWS Resiliency
  - ○ MKV-A Update
  - ○ ISSTAWS update
  - ○ TUBB EGPWS Data Display (TEDD)
- ○ Updates for Hybrid-Inertial Resiliency
- ○ GPS RFI Simulation & Crew Training

Resilient

All airplane systems are resilient to GPS RFI.

- ○ Comprehensive review of GPS User Systems' design requirements & philosophy
- ○ Interference Resistant Avionics technologies
- ○ Next Generation GNSS Receivers (DFMC)
- ○ Controlled Reception Pattern Antenna (CRPA)

777 GPS Event Monitor (GEM) Regional Symptom Maps: All Symptom Rollup



Observations

- Data shows a global increase in GPS interference occurrences with localized decreases in certain FIRs

Top 10 FIRs by Interference Occurrence Rate

1. Ankara (LTAA) - 77%
2. St. Petersburg (ULLL) – 71%
3. Minsk (UMMV) – 69%
4. Yangon (VYYF) – 62%
5. Moscow (UUWV) – 58%
6. Tel Aviv (LLLL) – 55%
7. Helsinki (EFIN) – 52%
8. Baghdad (ORBB) – 52%
9. Samara (UWWW) – 50%
10. Aktobe (UATT) – 45%

Note: Individual symptom maps w/ symptom initialization locations available in backup slides

Time trends of symptom occurrence and recovery rates also available in backup slides

GPS Event Monitor Data Summary

- GPS Event Monitor Report is installed on **841** 777s and **45** 787s across **37** different operators
- **777** data is collected from **June 25, 2024 – May 27, 2025, 787** data is collected from **April 1, 2025 – May 27, 2025**
- During data collection, this group of airplanes flew **305,510** total flights and reported a GPS Event on **90,532** of those flight legs
- **Accuracy of symptom rates and locations will improve as more aircraft are equipped with the GPS Event Monitor Report**

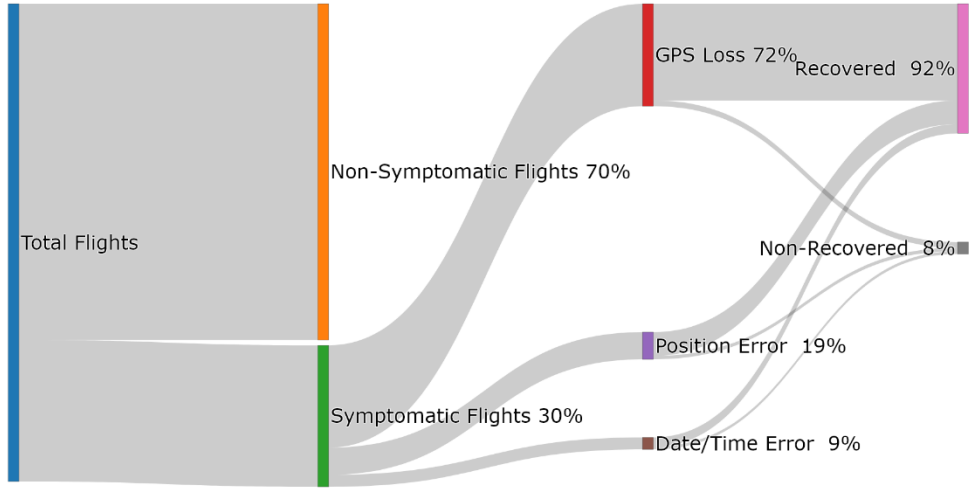
Receiver Type	Recovery Rate from All Symptoms	Recovery Rate from GPS Loss	Recovery Rate from Position Error	Recovery Rate from Date/Time Error
All Receivers	92%	94%	88%	77%
777 GLU-920	83%	90%	74%	52%
777 GLU-925	93%	95%	88%	85%
777 GLU-2100 (Phase 1)	90%	98%	95%	45%
777 IMMR	96%	99%	93%	62%
787 INR	88%	95%	82%	93%

Note: Receiver type recovery rates not directly comparable due to differing exposure to various interference environments

Observations

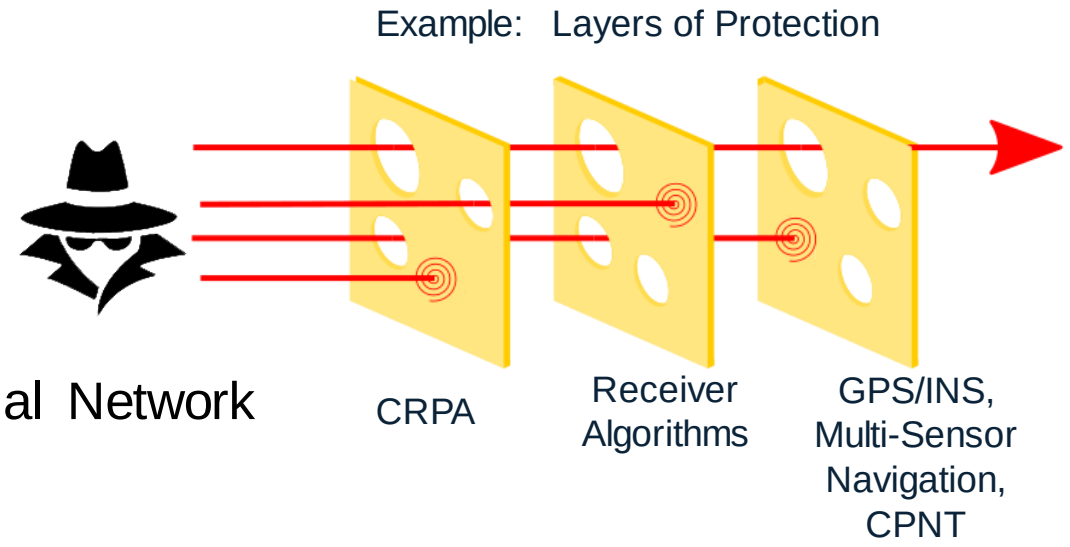
- **~30% of all flights completed during data collection experienced GPS interference symptoms**
- **Of the symptomatic flights:**
  - **72% experienced GPS Loss symptoms (Low Sat Count, Receiver Not in Nav Mode)**
  - **19% experienced Position Error symptoms (Position Shift, Altitude Shift, Large VFOM)**
  - **9% experienced Date/Time Error symptoms (Date Shift or Time Shift on GPS or AIMS)**
- **92% of symptomatic flights recovered from symptoms prior to landing**

Global Interference Trends



Technology Options

- **Resilience at the Operational Level**
  - Detection and alerting systems (non-aircraft)
  - NOTAMs
  - Backup Navigation Capabilities – Resilient Operational Network
  - Alternative Operations
- **Toughening at the Source**
  - More capable signals (e.g. DFMC GNSS with modernized signals)
  - Signal Authentication (OSNMA, SBAS Authentication, Chimera, etc.)
- **Toughening GNSS Receivers/User Equipment (UE)**
  - RFI detection and mitigation in the receiver (many methods)
- **Mitigation at the antenna level**
  - Controlled Reception Pattern Antennas (CRPAs)
- **Toughening at the Airplane Level**
  - Improved multi-sensor navigation (GNSS/INS, Improved source selection, etc.)
  - Complementary PNT systems (CPNT)



Mitigations at Multiple Levels are Needed

- **Technological solutions to make GNSS more robust exist**
  - Some relatively near-term actions are being taken to make GNSS RFI less disruptive
  - Some technology solutions are longer term (e.g. next gen receivers, adaptive antennas etc.)
  - Robustness can be enhanced at the source (e.g. signal authentication)
- **There is a limit to how robust GNSS can be made**
  - Reversion to alternative sources of position and timing will continue to be part of the overall solution
    - Resilient Operational Networks (RON) of conventional navigation aids
  - Reversion to inertial positioning for outages of limited duration
  - Improvements/evolution of existing navigation aids are being pursued to enable Performance Based Navigation (PBN) operations to be maintained in essential airspace
  - Development of new Complimentary PNT (CPNT) sources would be beneficial
    - New systems such as next generation DME, eLORAN or LDACS should be developed to support navigation and time transfer
    - Signals of Opportunity (enable use of non-aviation PNT capabilities as back up capability?)
- **Time Synchronization Requirements need to be studied**
  - GNSS allows for everyone to be on the same time reference. However, inadequate consideration has been given to the required performance (i.e. accuracy, integrity, continuity) of time synchronization.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