Characterization of ADS-B Performance under GNSS Interference

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Objective

- To examine ADS-B (Automatic Dependent Surveillance-Broadcast) behaviors during GNSS interference events and develop methods to use ADS-B for rapid GNSS interference detection and localization

- Bottom line up front:
  - ADS-B is a good tool for identifying interference, but there are several challenges to implementing it reliably

What is ADS-B

- Automatic Dependent Surveillance-Broadcast (ADS-B) is a technology where aircraft broadcast their estimated position
  - Position and velocity messages output every 0.4 – 0.6 sec
    - No interrogation signal is required to initiate the broadcast
  - Position is determined by satellite navigation
  - Nearby aircraft use these transmissions to obtain situational awareness of surrounding aircraft and maintain adequate separation
  - A network of ground and/or satellite receivers use messages to allow Air Traffic Control (ATC) to track aircraft location
    - ADS-B can supplement or replace radar tracking of aircraft location
    - ADS-B is more accurate than radar and has better coverage
- ADS-B is mandated in the U.S. and other parts of the world

Application to GNSS Interference Detection

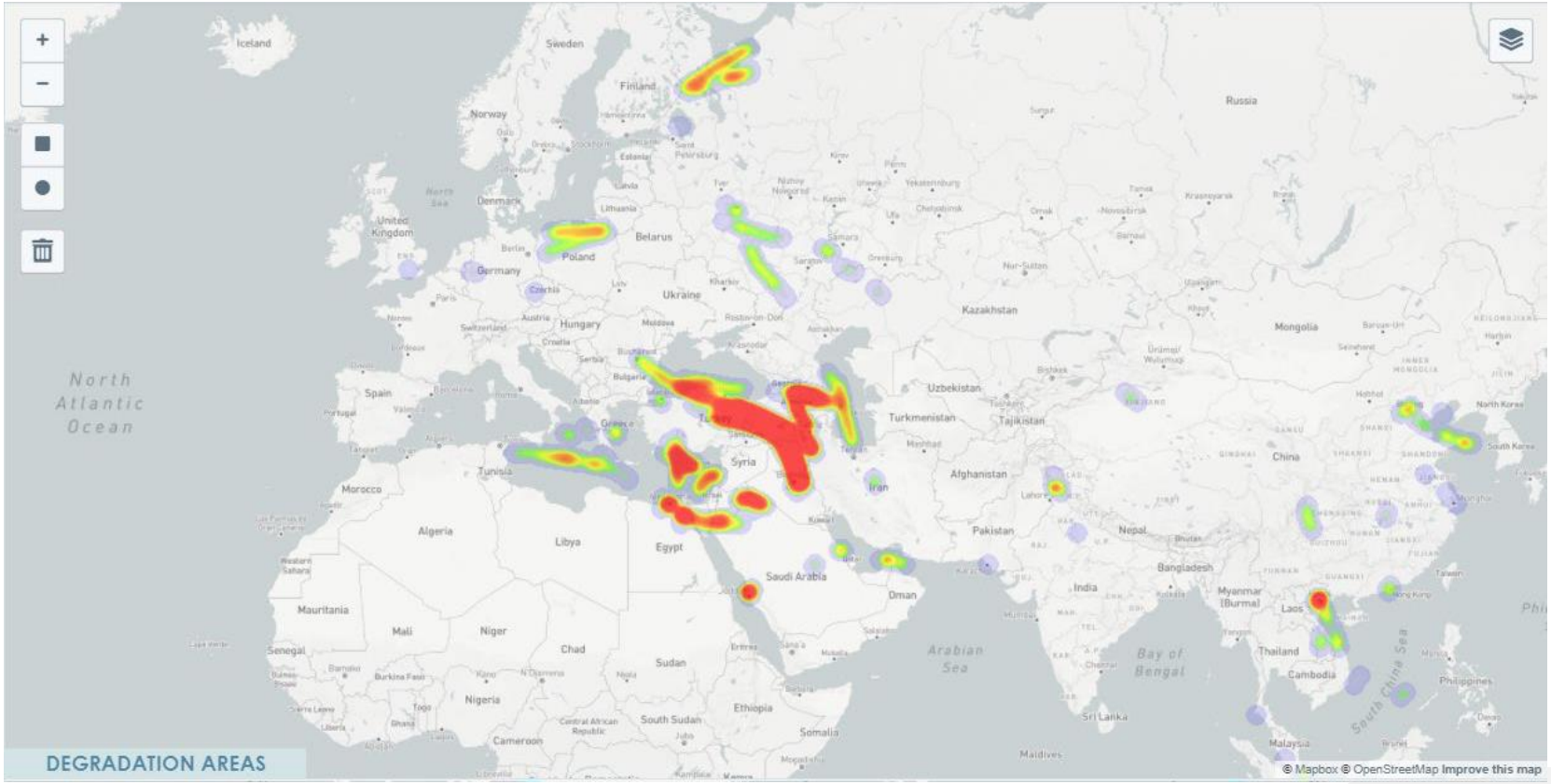
- ADS-B was not designed to support interference detection
- ADS-B position is derived from GNSS
- Interference to GNSS at the aircraft will degrade the position accuracy and the associated confidence bounds
- Broadcast data demonstrating such degradations may be indicative of interference
- If multiple aircraft within a region exhibit such degradations, then RFI may be inferred as a potential cause

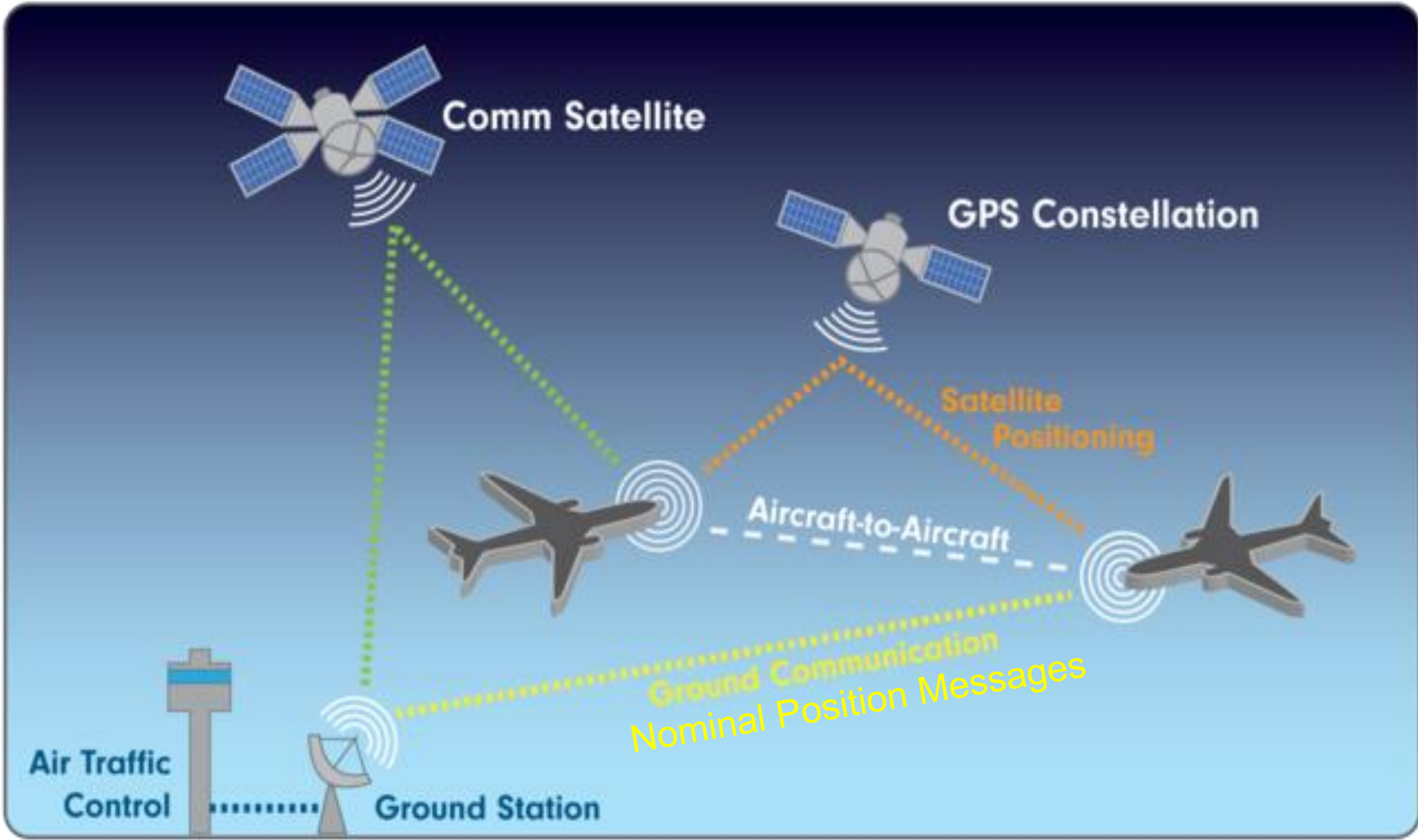
- Initially proposed and developed by EUROCONTROL in 2016
  - Noticed a significant increase in reported GPS outage events

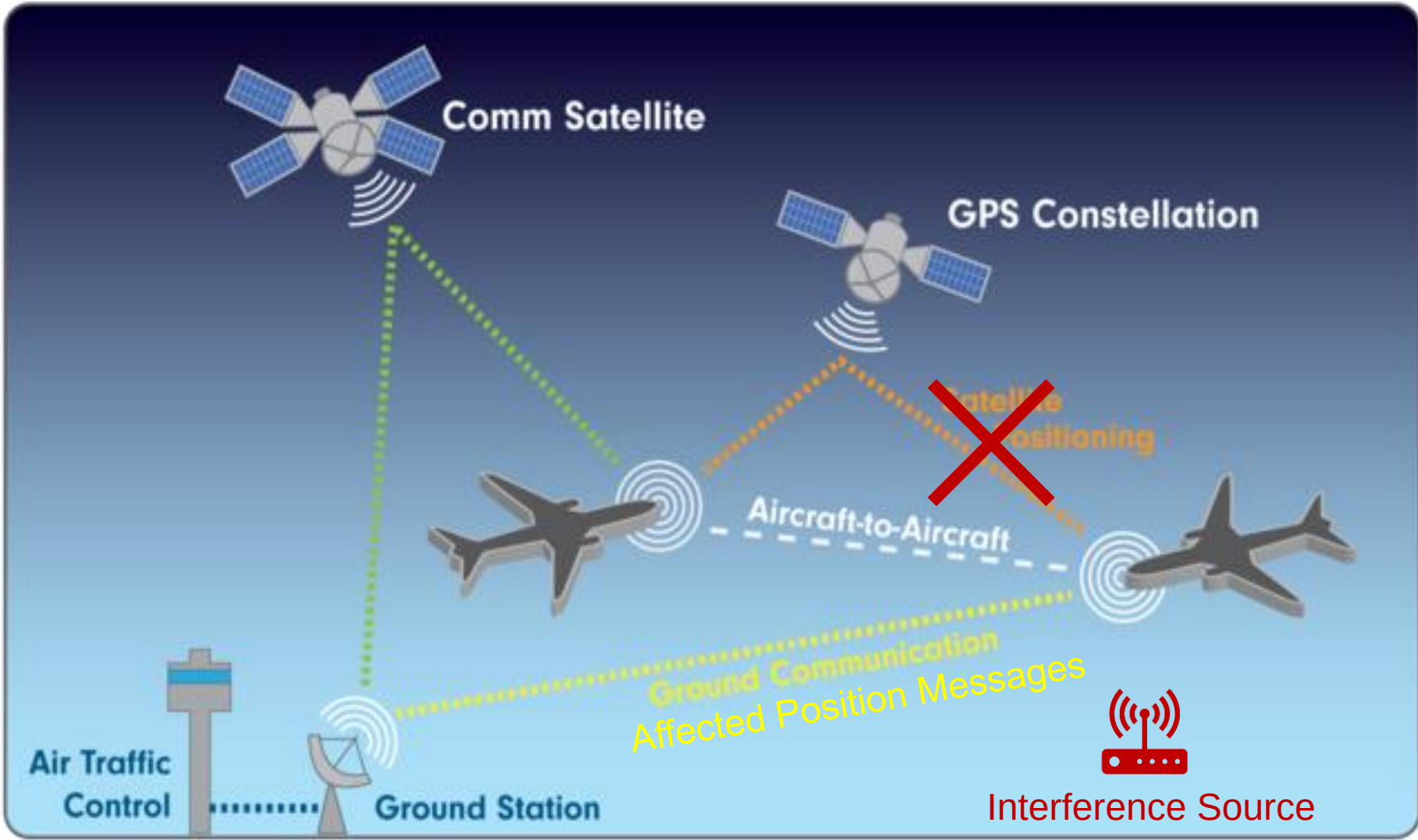
ADS-B and Automatic Identification System (AIS)

- AIS has been used to identify interference events around the world
  - Spoofing in the Black Sea
  - Circle spoofing in Shanghai, Iran,etc.
- ADS-B can provide similar information with better sampling of landmasses

GNSS RFI as detected by Airbus Aircraft, 2nd Sem 2020




Comm Satellite
GPS Constellation
Satellite Positioning
Aircraft-to-Aircraft
Ground Communication
Nominal Position Messages
Air Traffic Control
Ground Station


Comm Satellite
GPS Constellation
Aircraft-to-Aircraft
Ground Communication
Affected Position Messages
Air Traffic Control
Ground Station
Interference Source

ADS-B Data

- ADS-B messages include:
  - Airborne position (~2 Hz)
    - ICAO aircraft identifier & position
    - Navigation Integrity Category (NIC)
  - Airborne velocity (~2 Hz)
    - ICAO aircraft identifier & velocity
    - Navigation Accuracy Category – velocity (NACv) - estimated velocity uncertainty (95% accuracy)
  - Operational status (~0.4 Hz)
    - ICAO aircraft identifier
    - Navigation Accuracy Category – position (NACp) - estimated position uncertainty (95% accuracy)
    - Surveillance Integrity Level (SIL)
- Messages are neither encrypted nor authenticated

Navigation Integrity Category (NIC:)

- The NIC is a number that represents the integrity bounding of the position measurements. It corresponds to a position containment radius (R_C)

Larger NIC values indicate better GNSS performance

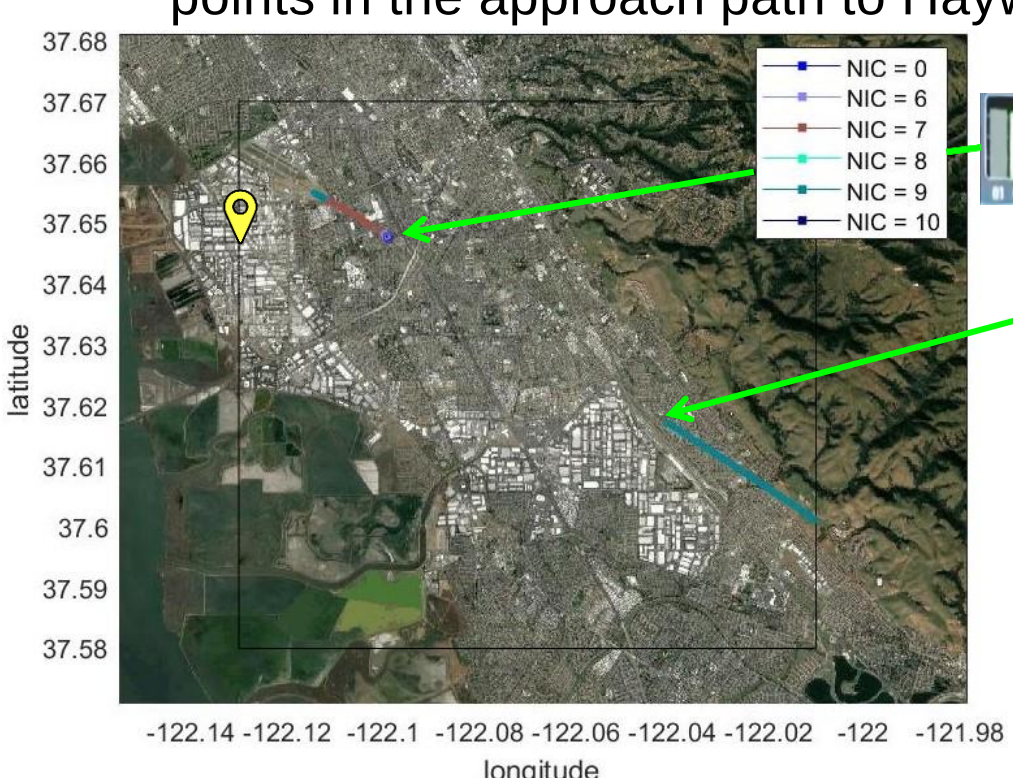
NIC	Containment Radius
0	Unknown
1	$R_C < 37.04$ km (20nm)
2	$R_C < 14.816$ km (8nm)
3	$R_C < 7.408$ km (4nm)
4	$R_C < 3.704$ km (2nm)
5	$R_C < 1852$ m (1nm)
6	$R_C < 1111.2$ m (0.6nm)
	$R_C < 926$ m (0.5nm)
	$R_C < 555.6$ m (0.3nm)
7	$R_C < 370.4$ m (0.2nm)
8	$R_C < 185.2$ m (0.1nm)
9	$R_C < 75$ m
10	$R_C < 25$ m
11	$R_C < 7.5$ m

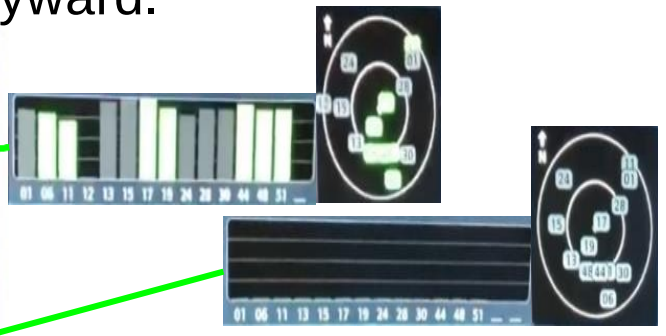
Uncovering the Effects of RFI on ADS-B

- Report from a local pilot who had experienced GPS outages on two flights in early 2019
  - Video available at https://www.youtube.com/watch?v=sIfm6orZlgc
- We participated in a jamming exercise at Edwards Air Force Base in September 2019
  - Collected airborne GNSS data including times and locations of successful jamming
- Eastern Mediterranean region
  - A well-known jamming location

Local Report of Interference

- A local pilot experienced GPS outages twice at very similar points in the approach path to Hayward.

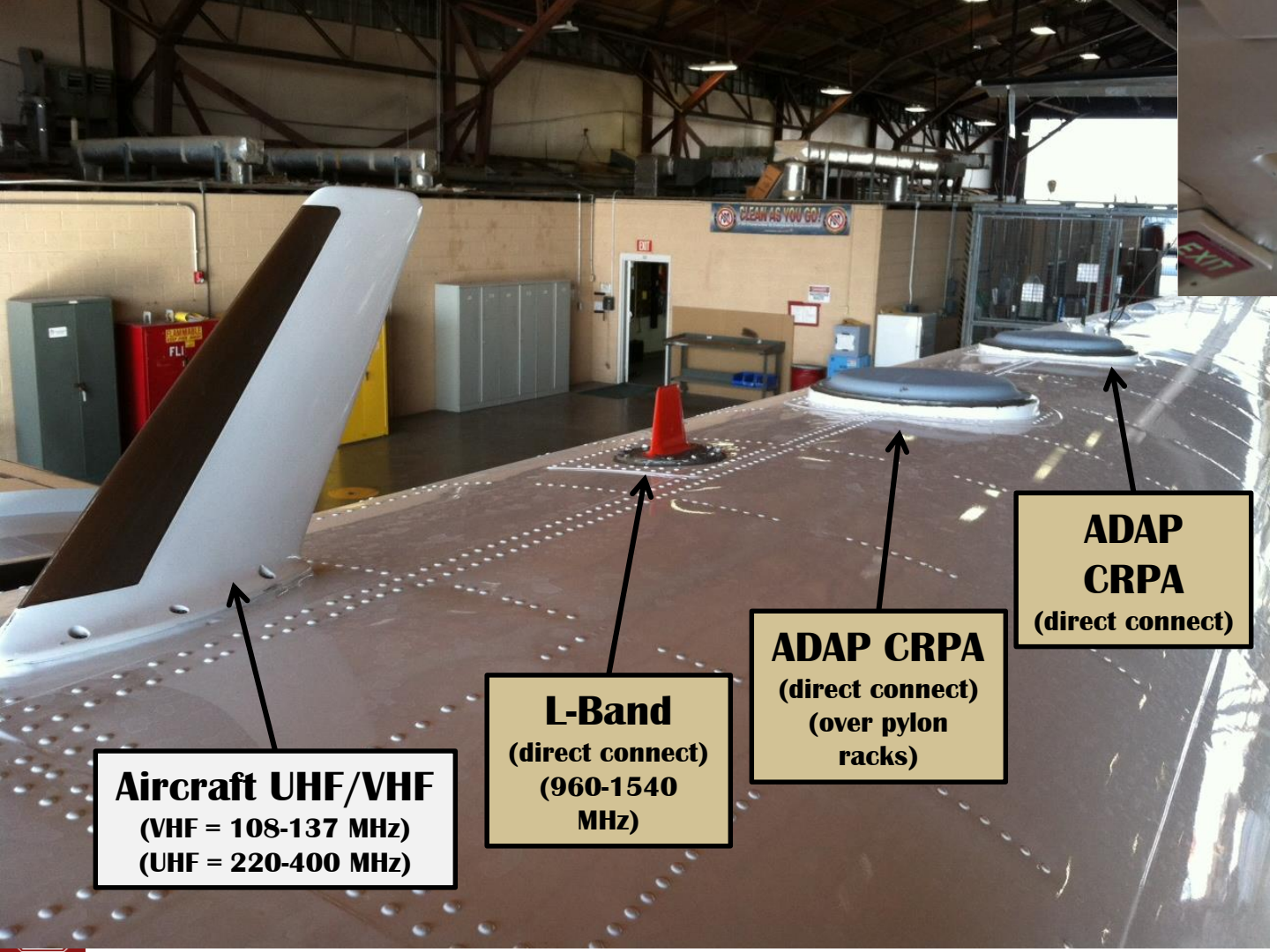




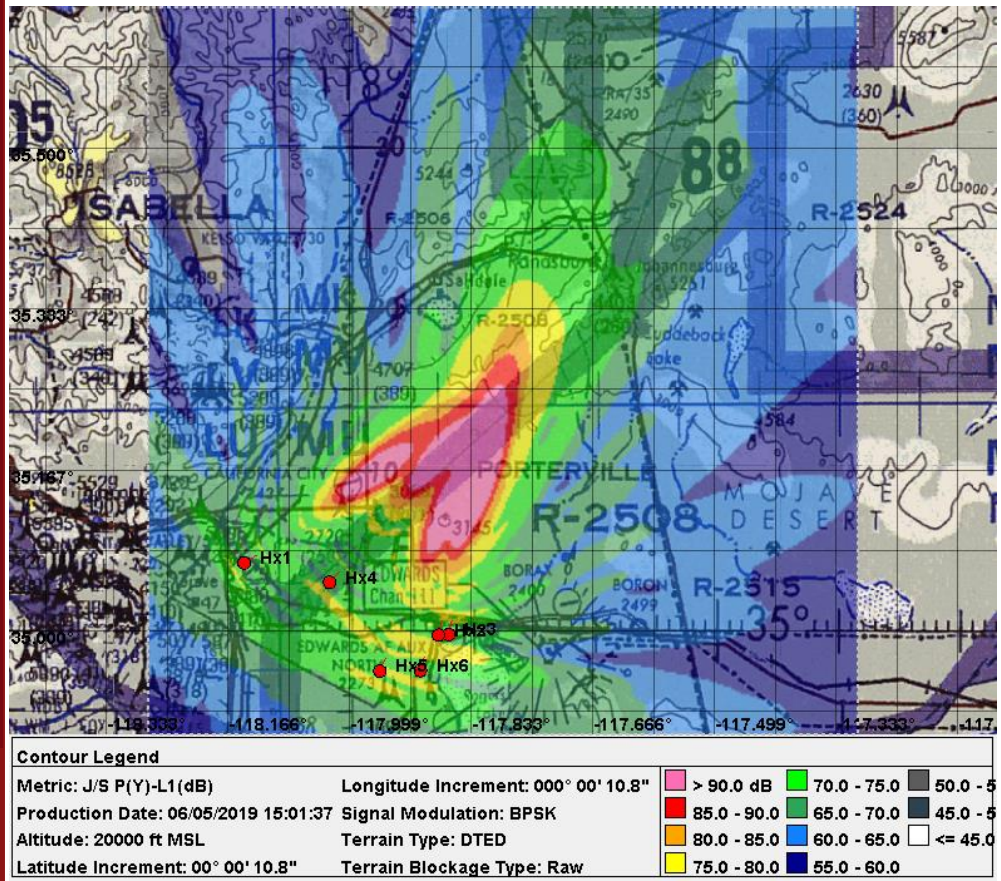
1. ADS-B position message output gaps

2. Variations in NIC value from reasonable values ≥ 7, down to 0

Test Aircraft at Edwards AFB


Aircraft UHF/VHF
(VHF = 108-137 MHz)
(UHF = 220-400 MHz)
L-Band
(direct connect)
(960-1540 MHz)
ADAP CRPA
(direct connect)
(over pylon racks)
ADAP CRPA
(direct connect)

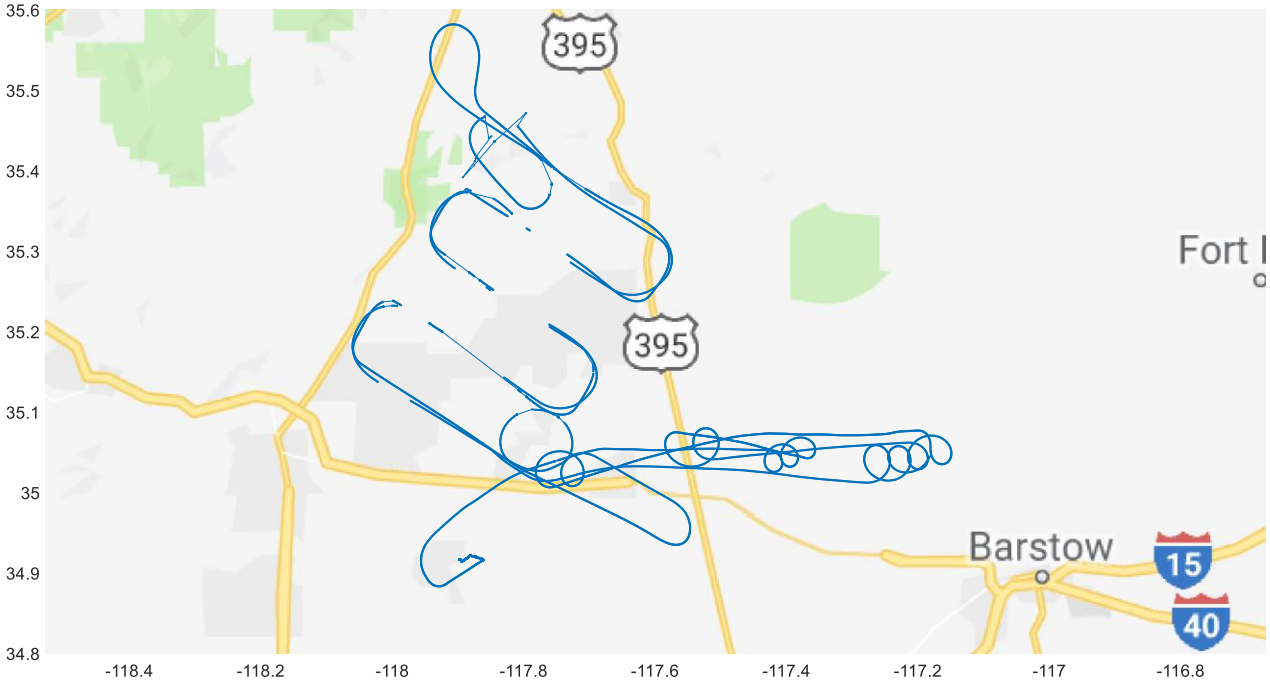
Interference Sources NAVFEST 2019



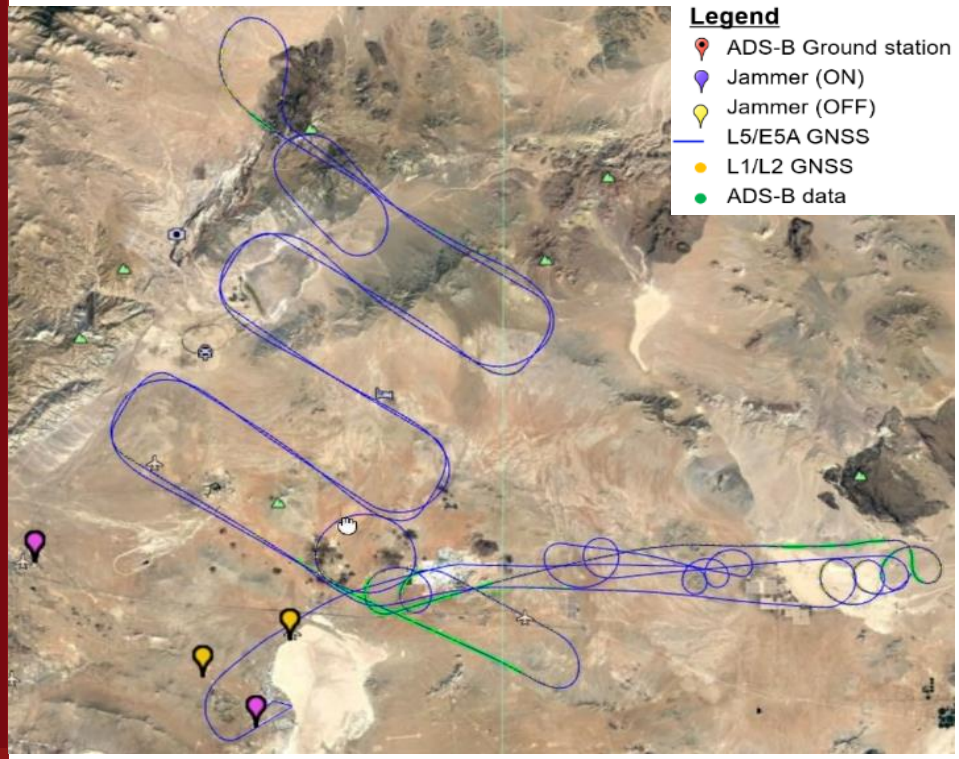
40 to 90 dB of jamming

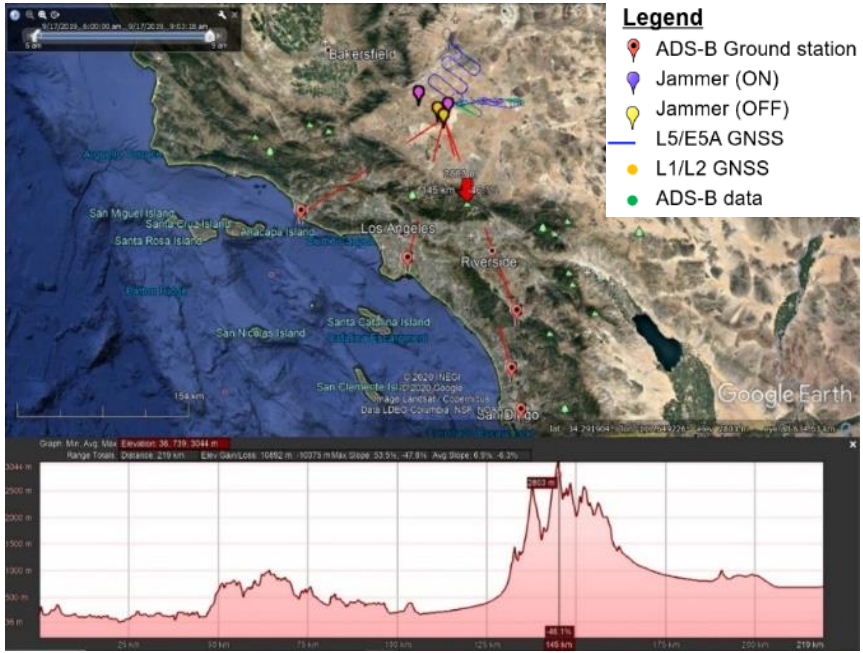
Compare radiated and anticipated interference power with measured power

GNSS positions during DT NAVFEST (9/17/2019)



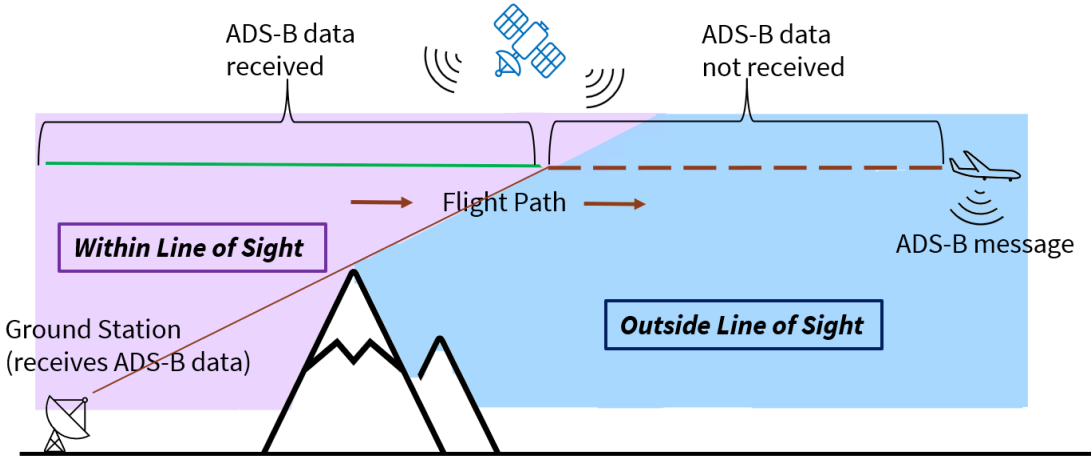
ADS-B Impact During DT NAVFEST (9/17/2019)





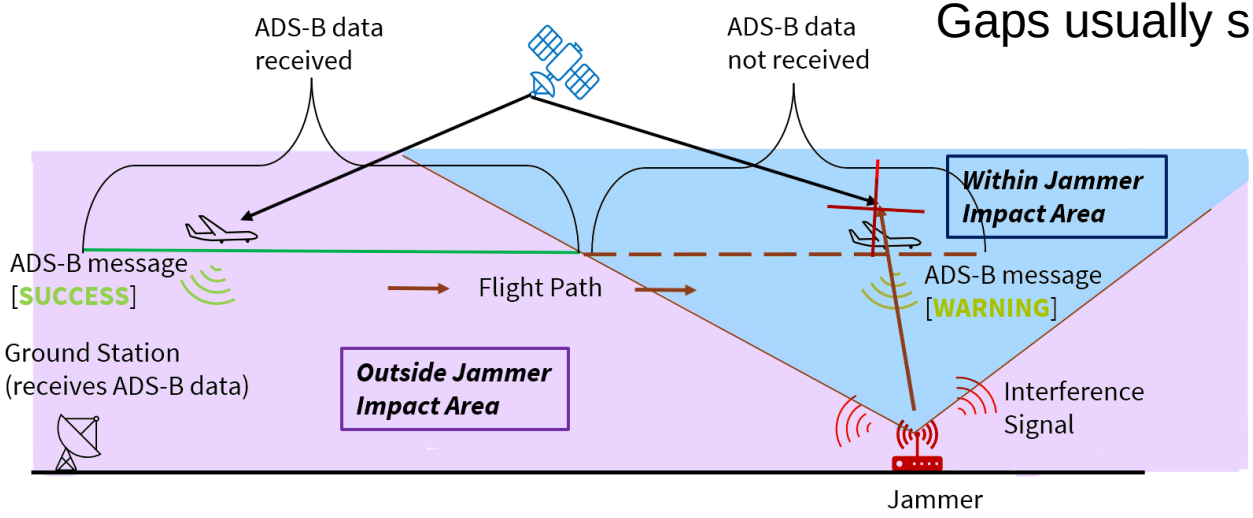
Flight Track Gaps

- Gaps in recorded flight tracks can occur for several reasons including jamming and terrain blockage



Normal Circumstance with Signal Blockage by Mountains

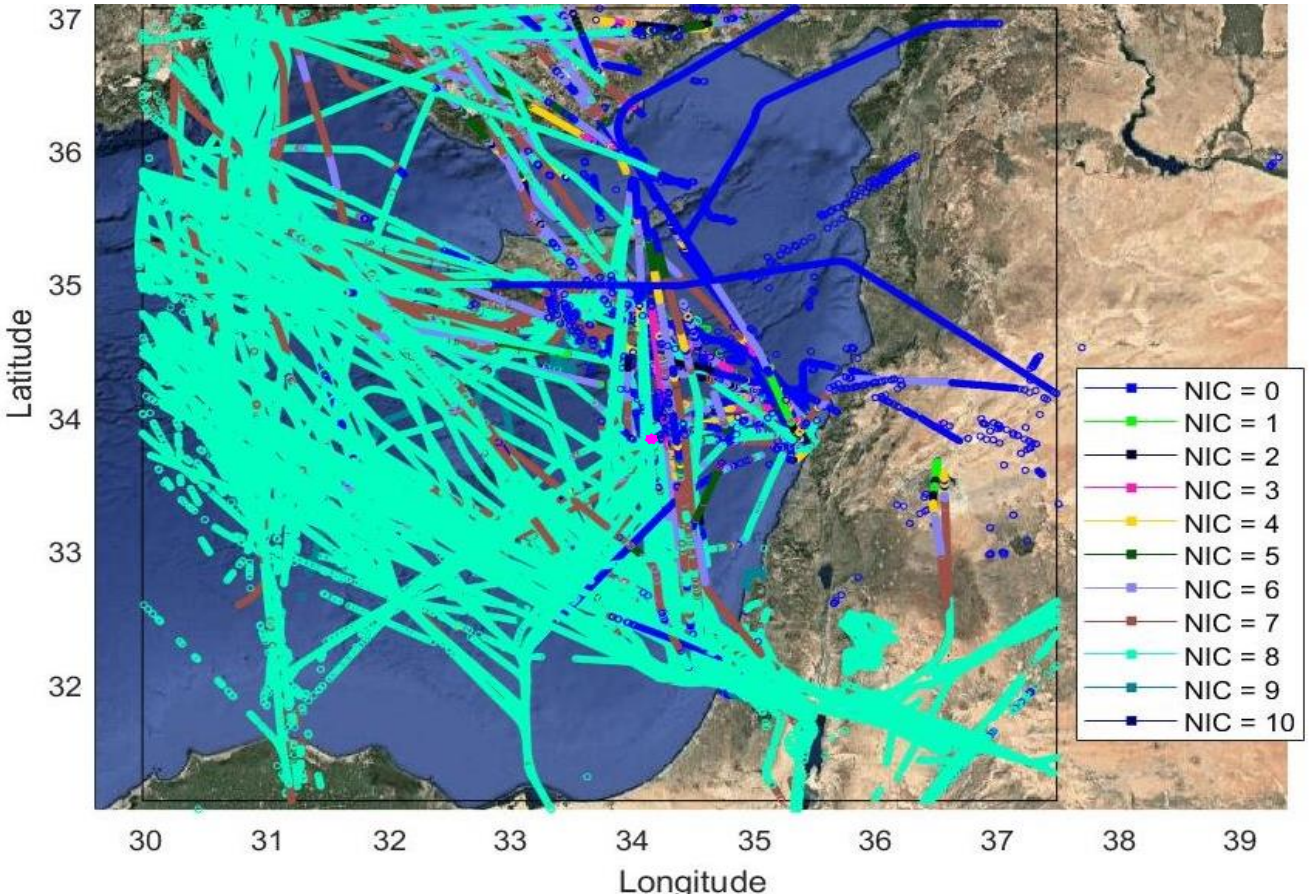
Gaps usually surrounded by good NIC values



Interference Event without Mountains

Gaps usually contain poor NIC values before and/or afterwards

Eastern Mediterranean (Cyprus Region)



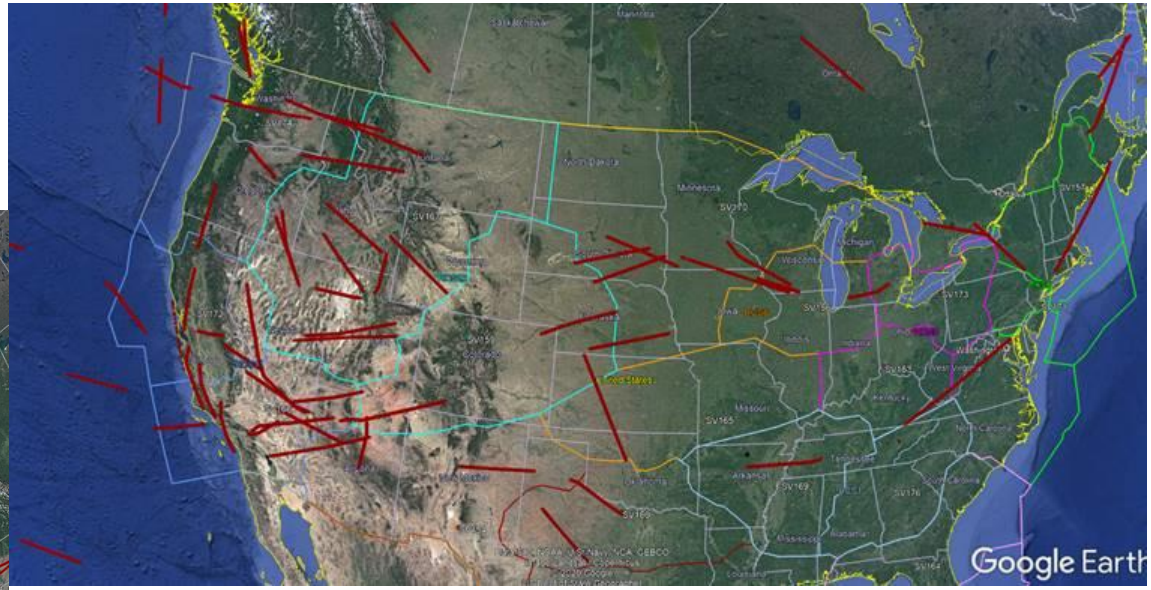
- Many flight paths affected
  - Experienced both position gaps and poor NIC values
- Affected area is very large

Jamming Effects on ADS-B

- Although data gaps were frequently associated with RFI events, there are many other causes of gaps
  - Gaps by themselves are not necessarily a good indicator of jamming
- The confidence parameters NACp, NACv, and NIC are better indicators of RFI
  - NIC is nominally required to be 7 or above
  - Values of 6 or below indicate possible degradation
  - For strong RFI it will typically drop to 0
  - Moderate RFI can lead to intermediate values, but so can poor geometry (e.g., caused by aircraft banking)
- A low NIC value with an associated gap is a strong indicator

SVN 74 Anomaly – September 20, 2020

- Broadcasted non-standard data along with a large clock error
- Not all aircraft showed impact (a few dozen), but aircraft with NICs = 0 are spread over a wide area under SVN 74 footprint
- Some GNSS receivers affected by anomaly



Figures courtesy Andy Leone at the FAA SBS program office

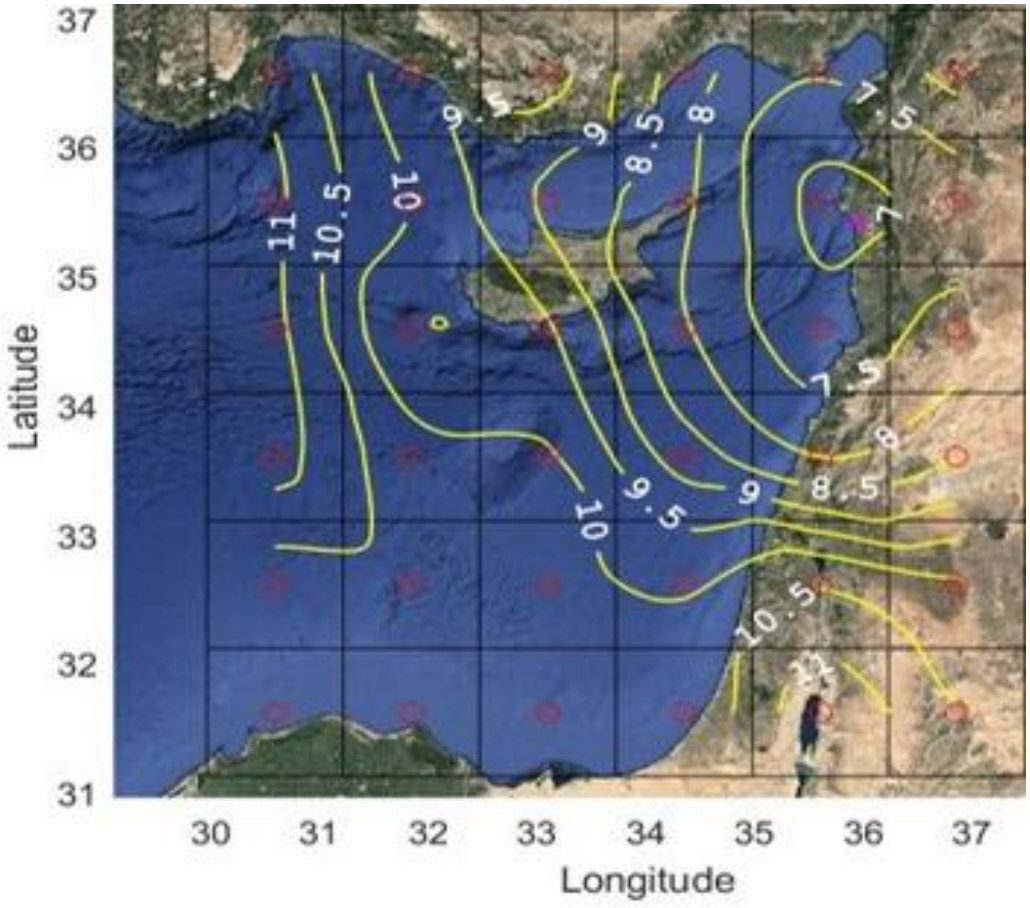
Spoofing Detection

- ADS-B could also be very effective at detecting spoofing
- Radar coverage is still available in most areas
- ADS-B ground receivers are synchronized, the network could be expanded to use trilateration to estimate the aircraft latitude and longitude
  - ADS-B reports most often use the barometric altimeter height
- Spoofing could be detected by comparing these independent position estimates against the broadcast positions
- The independent estimates can be used to fill in position gaps

Summary

- U.S. airspace is sampled by > 45,000 flights every day
  - > 200,000 globally
- These aircraft sample the GNSS RF environment and broadcast information that may be used to detect the presence of interference
- ADS-B was not designed for RFI detection, so care must be taken to properly distinguish RFI events from other issues
  - Active proposals to include more direct information (e.g., C/N0)
- Work is being done by many different organization to parse this data and identify effective means of detection and localization
  - Expect ADS-B to be increasingly used for RFI detection & localization

Localization Contour



- Working on methods to determine the location of the jammer
- Match observed performance against expected performance for a grid of possible jammer locations