Characterization of ADS-B Performance Under GNSS Interference

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Objective

To achieve rapid GNSS interference detection and localization using ADS-B (Automatic Dependent Surveillance-Broadcast)

Bottom line up front:

- ADS-B is a good tool for identifying interference, but there are several challenges to implementing it reliably
  - Airborne sensors very good at detecting interference
  - Capable of good localization performance under ideal conditions, but more often conditions are less than ideal

Navigation Integrity Category (NIC)

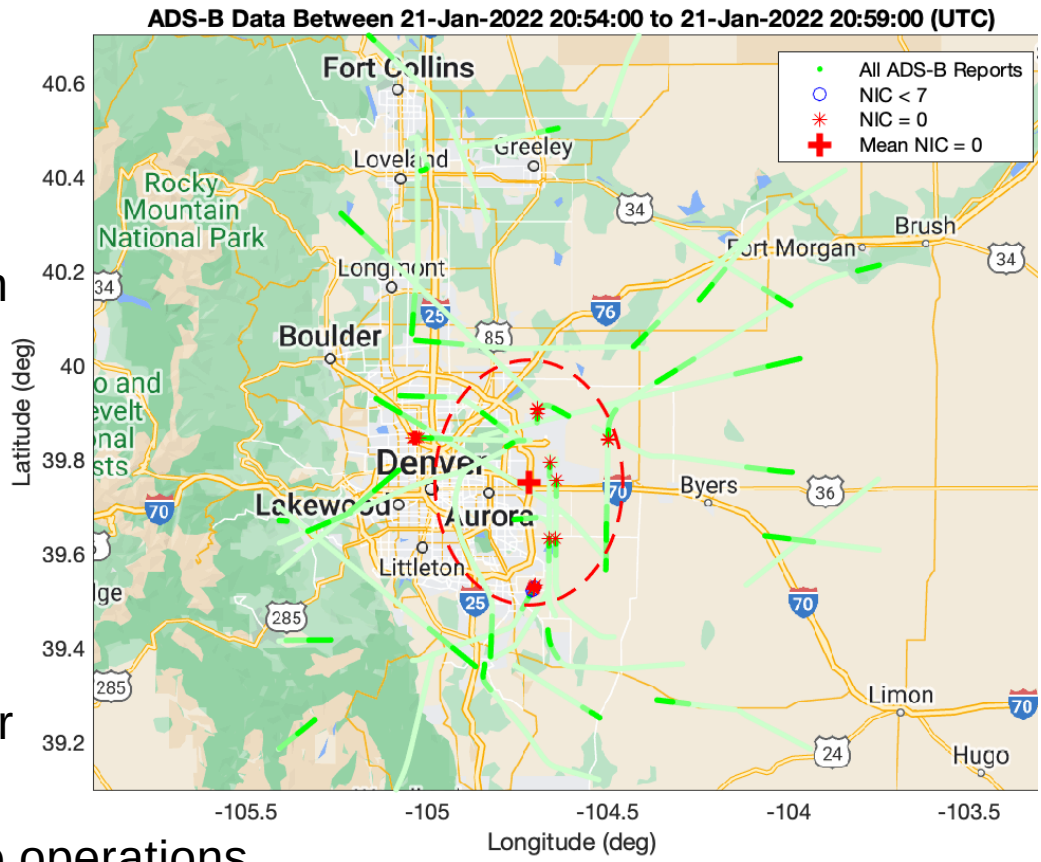
NIC specifies an integrity containment radius that the current horizontal position is guaranteed to be within, with 99.999% probability.

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

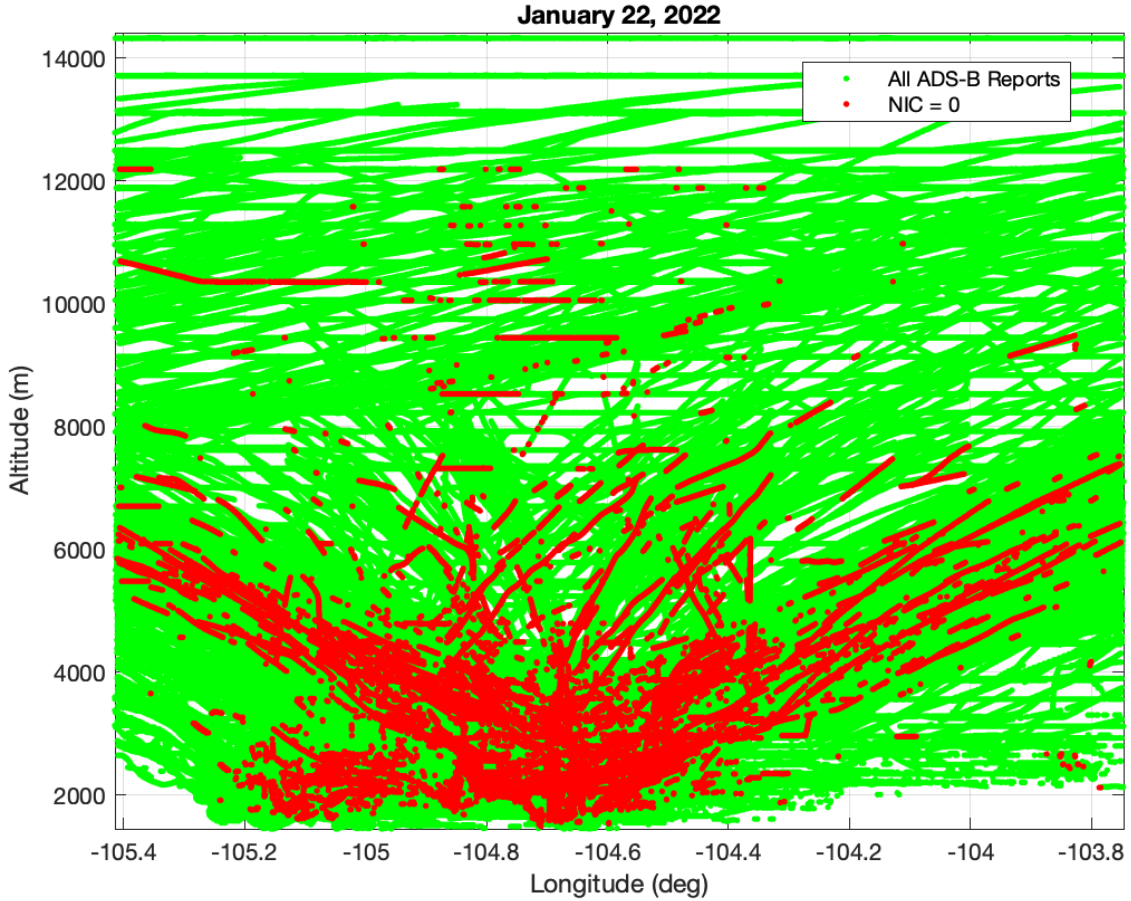
Nominal condition

2022: Denver Jamming Event

- On January 21, 2022, a GPS interference event occurred in the vicinity of Denver airport
- Event persisted for nearly 33 hours
- Interference source traced to nearby location
- NOTAM issued indicating use of GPS could be unreliable for 50 NM radius around airport
- Affected arrival and departure operations
- Local rail usage including positive train control impacted
- Some disruption of cell tower time synchronization



January 22, 2022 ADS-B Data



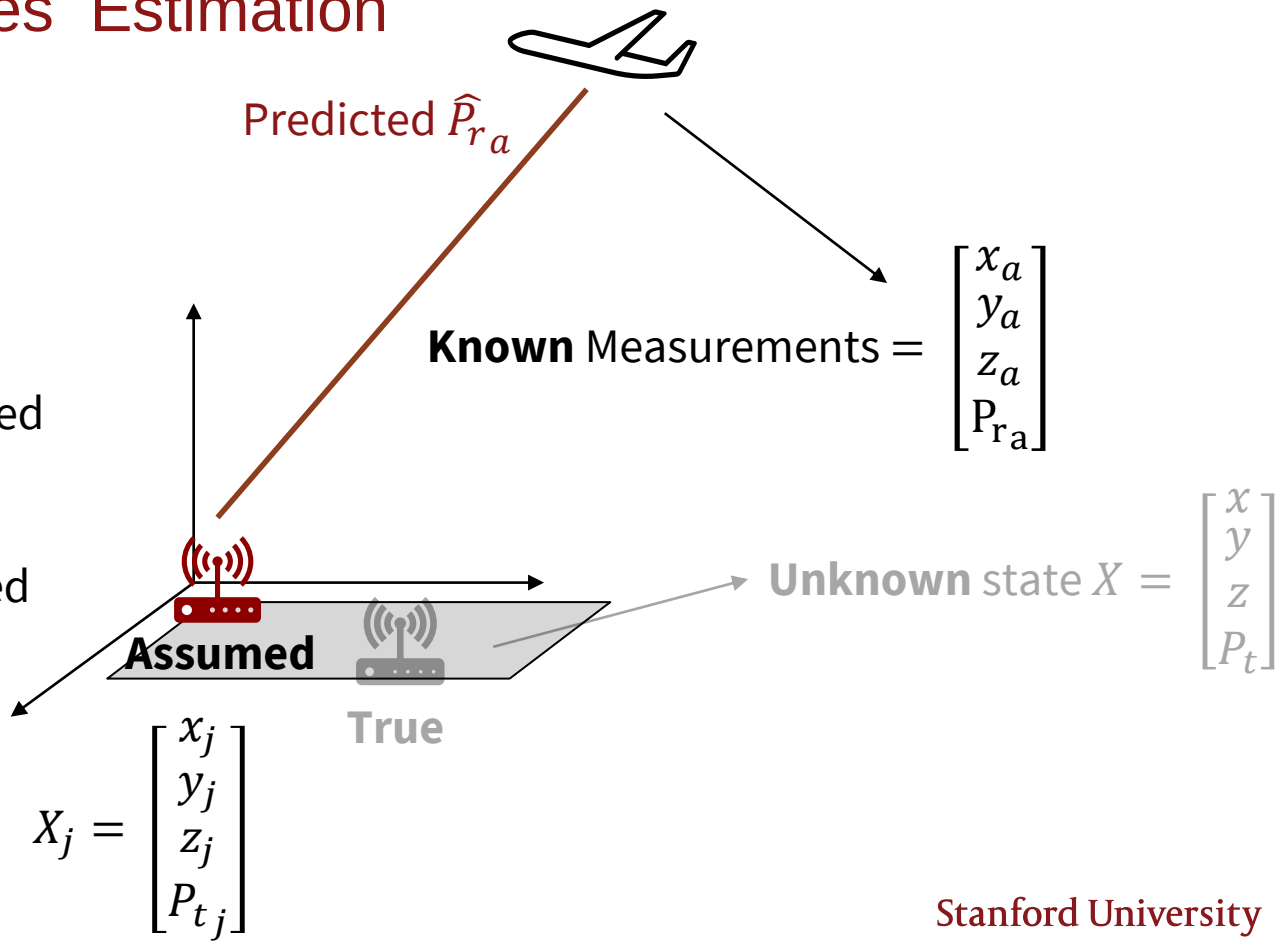
- Within First 30 seconds of event, it was already possible to get a good initial estimate of the jammer location
- Not always this easy, depends on aircraft distribution and jammer characteristics

Least Squares Estimation

P_r: received jamming power on aircraft

P_t: jammer transmitted jamming power

x,y,z: in Earth centered Earth fixed frame



Inferred measured P_r from NIC

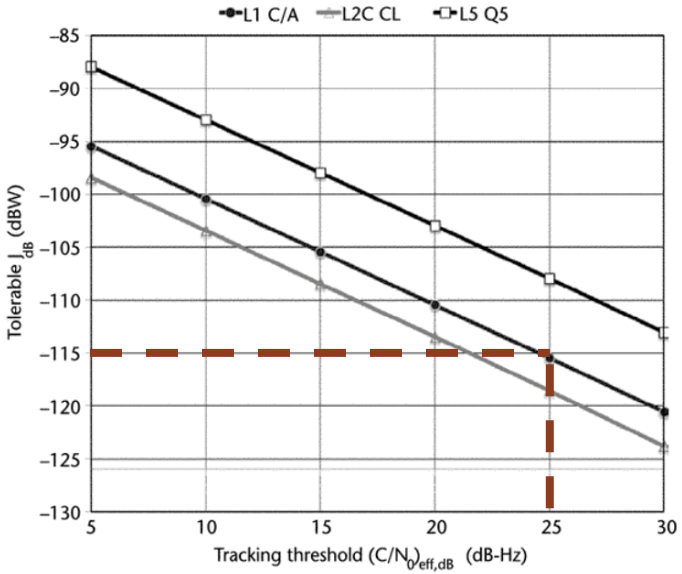
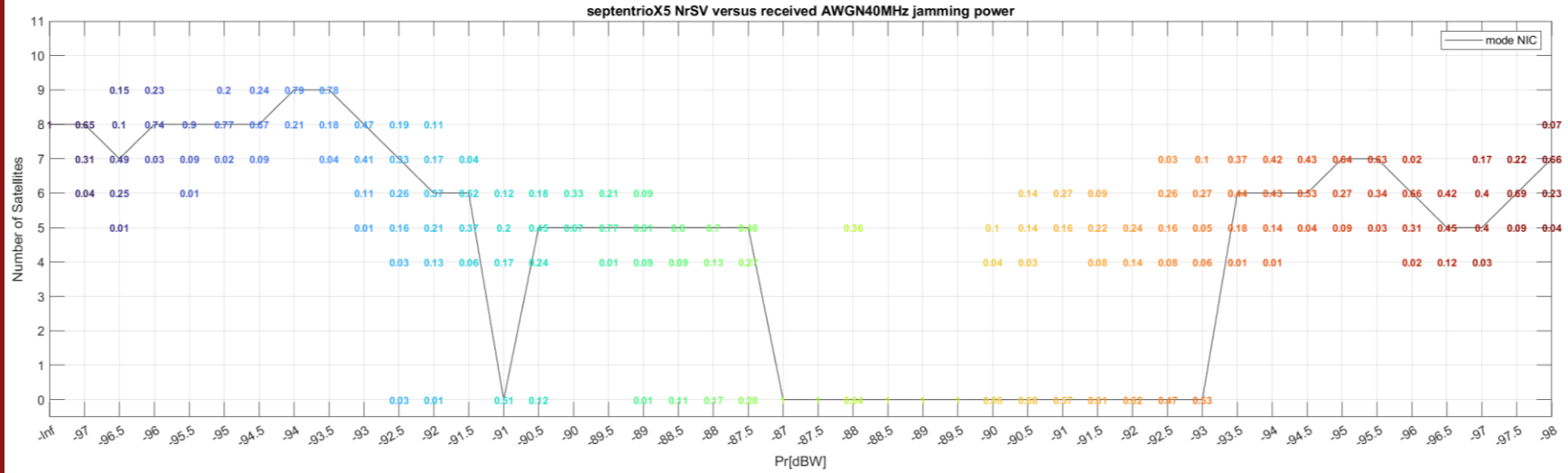


Figure 9.3 Tolerable I_{dB} as a function of tracking threshold for L1 C/A, L2 CL and L5 Q5 signals.

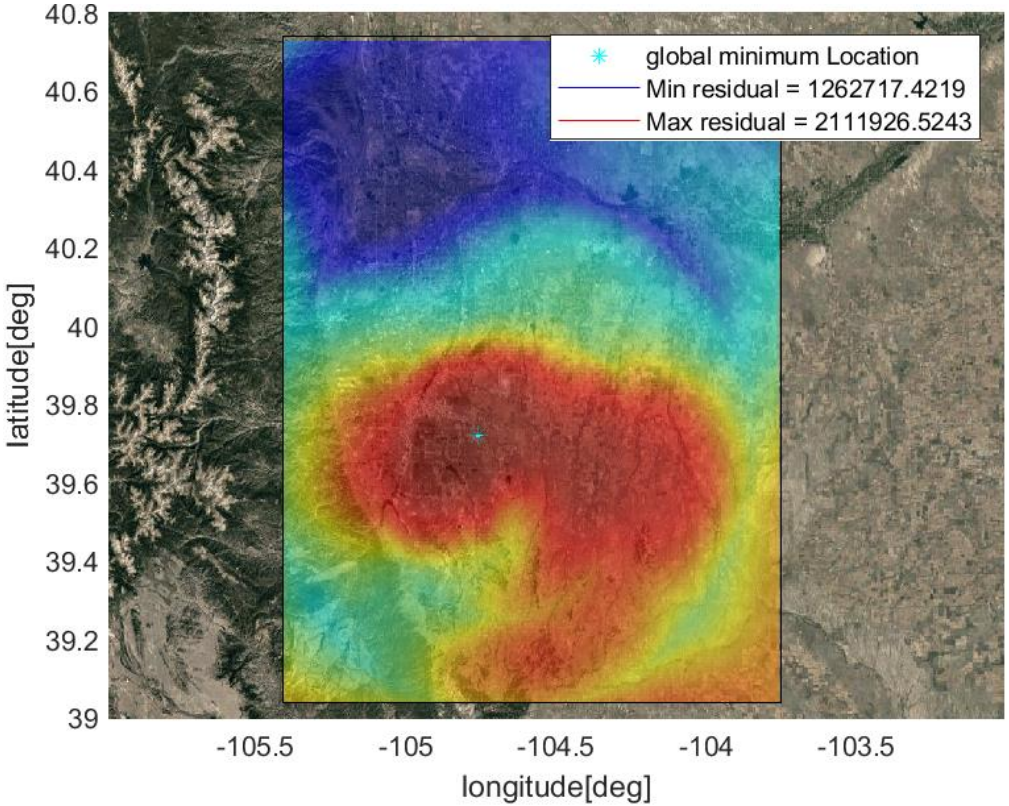
Kaplan, E. D., and Hegarty, C. (2017). *Understanding GPS/GNSS: Principles and applications*.

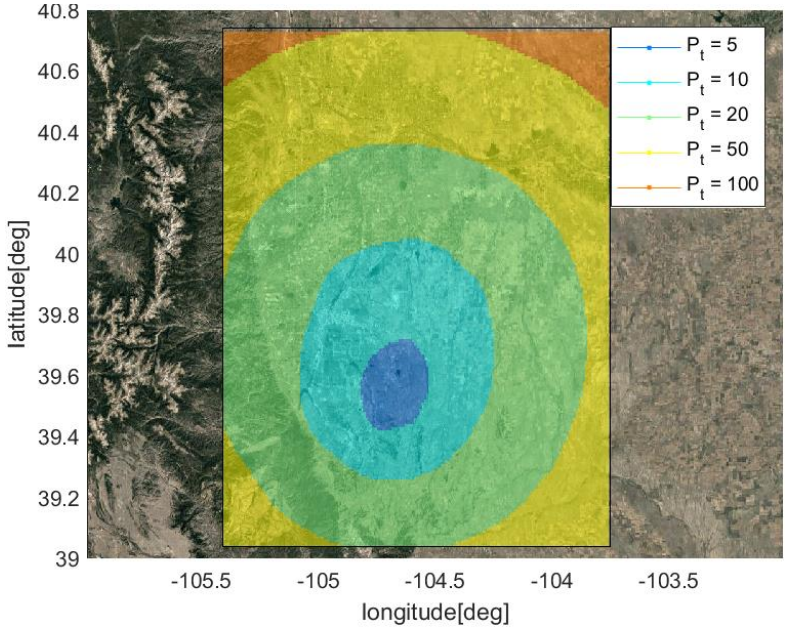
NIC	Pr[dBW]	
		High power
0	[-100, 0)	Low power
1	[-105, -100)	
2	[-110, -105)	
3	[-115, -110)	
4	[-120, -115)	
5	[-125, -120)	
6	[-130, -125)	
7	(-∞, -130)	On the boundary
		Far away


septentrioX5 NrSV versus received AWGN40MHz jamming power
mode NIC
Number of Satellites
Pr[dBW]

septentrioX5 NIC versus received AWGN40MHz jamming power
mode NIC
NIC
Pr[dBW]

Local optimal P_t





Gaps in ADS-B Reports

- Aircraft may be beyond Line-Of-Sight (LOS) of ADS-B ground stations

- Aircraft affected by RFI may not be able to report their position
  - NIC value change is used to infer as to whether aircraft is beyond LOS or possibly jammed

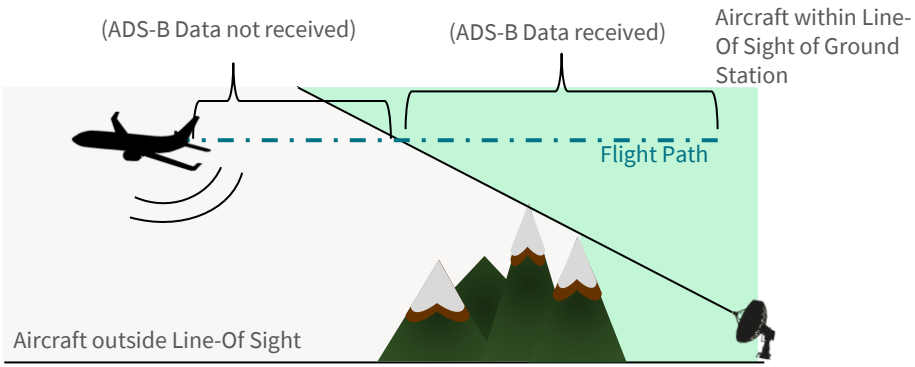


Figure 2 Illustration of Aircraft beyond Line-Of Sight

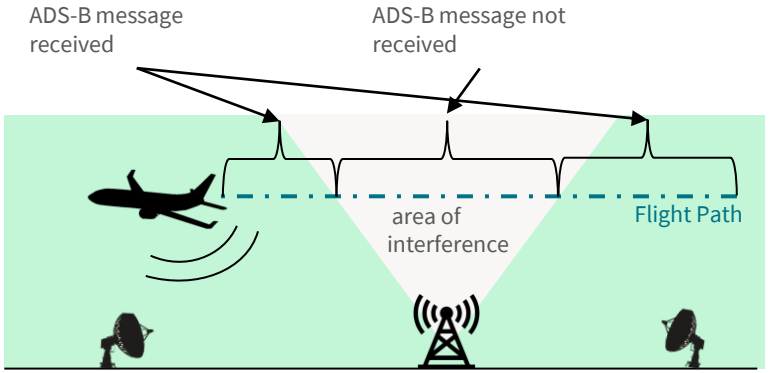
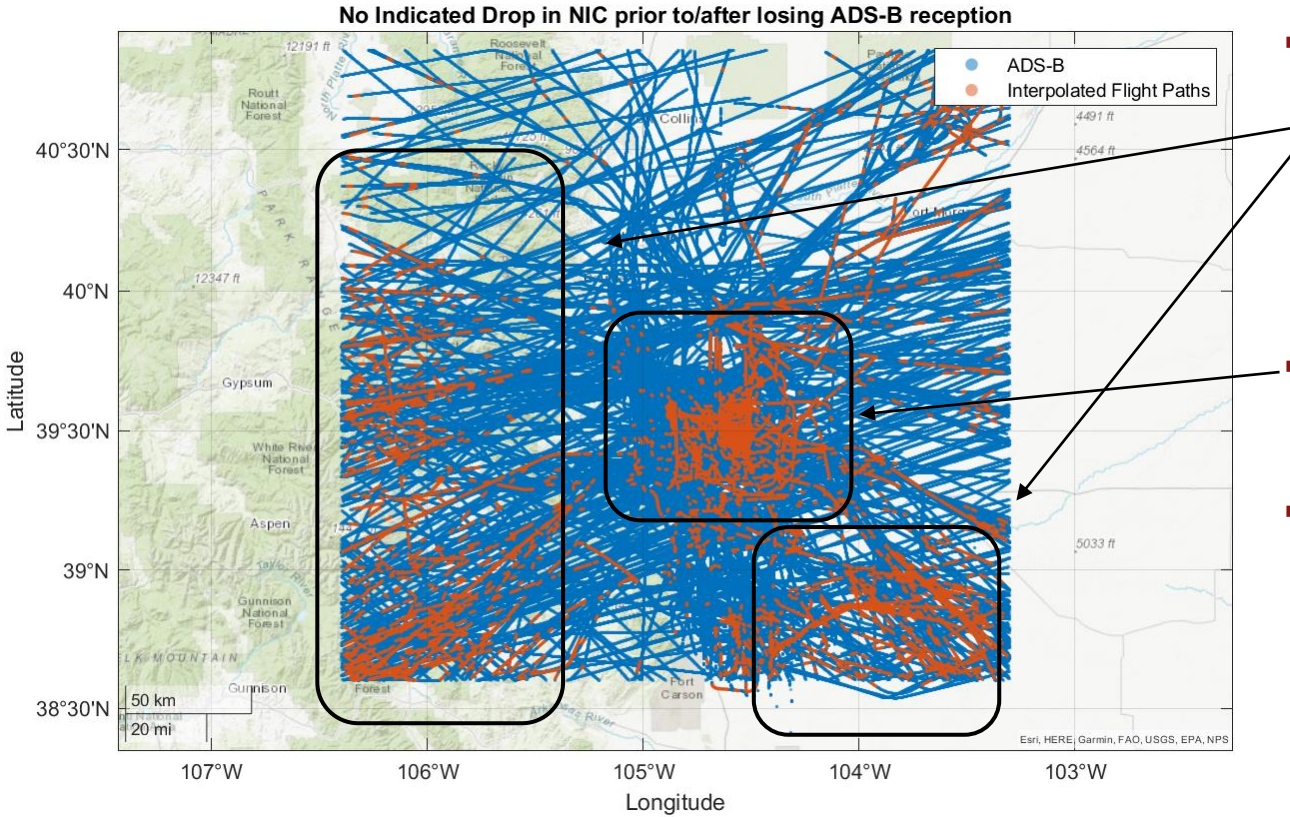


Figure 3 Illustration of Aircraft affected by local jamming sources

Interpolation Results

Prior to Interference: Jan 21 (0 UTC) – Jan 21 (2059 UTC)

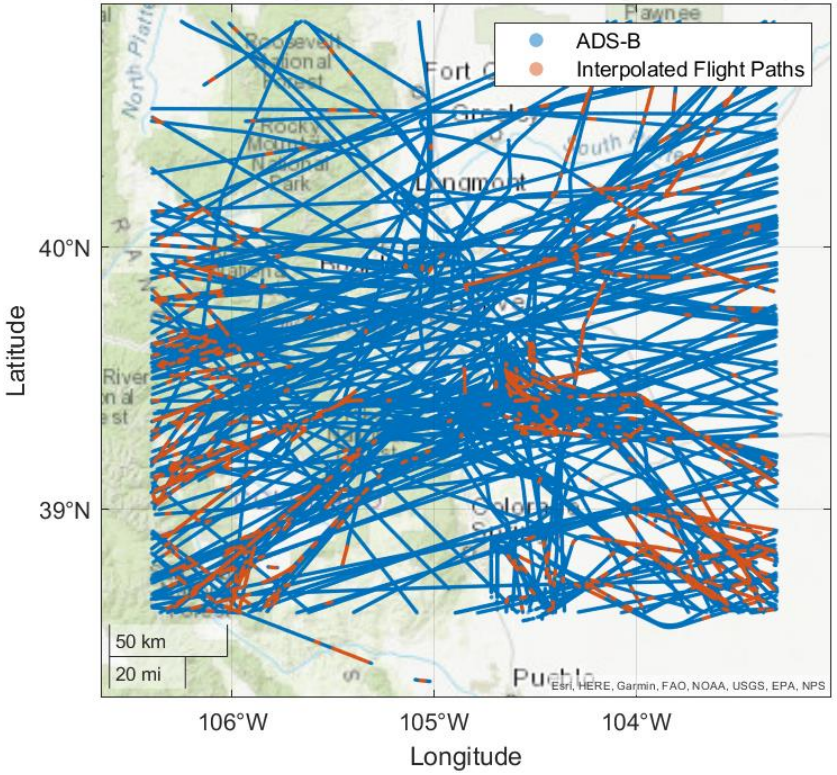


- High terrain, mountain areas experience intermittent loss in signal, as well other rural areas outside of KDEN
- Also susceptible to aircraft performing high bank turns
- Consistently noticed in dataset before and during reported interference

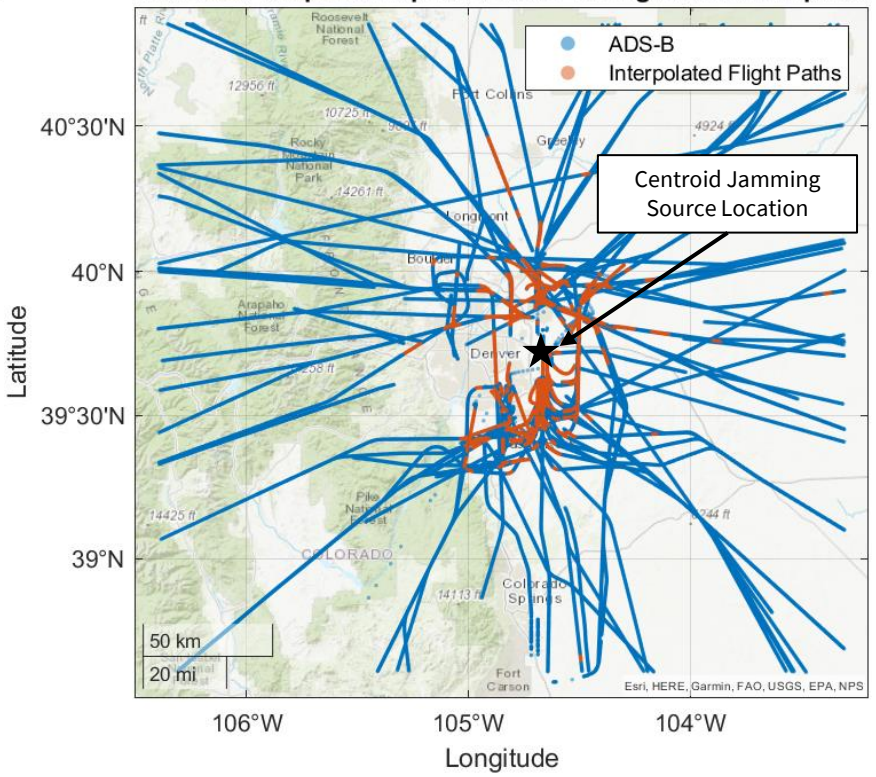
Interpolation and Localization Results

During Interference: Jan 21 (2100 UTC) – Jan 22 (0659 UTC) (1400 – 2400 Local Time)

No Indicated Drop in NIC prior to/after losing ADS-B reception



Indicated Drop in NIC prior to/after losing ADS-B reception



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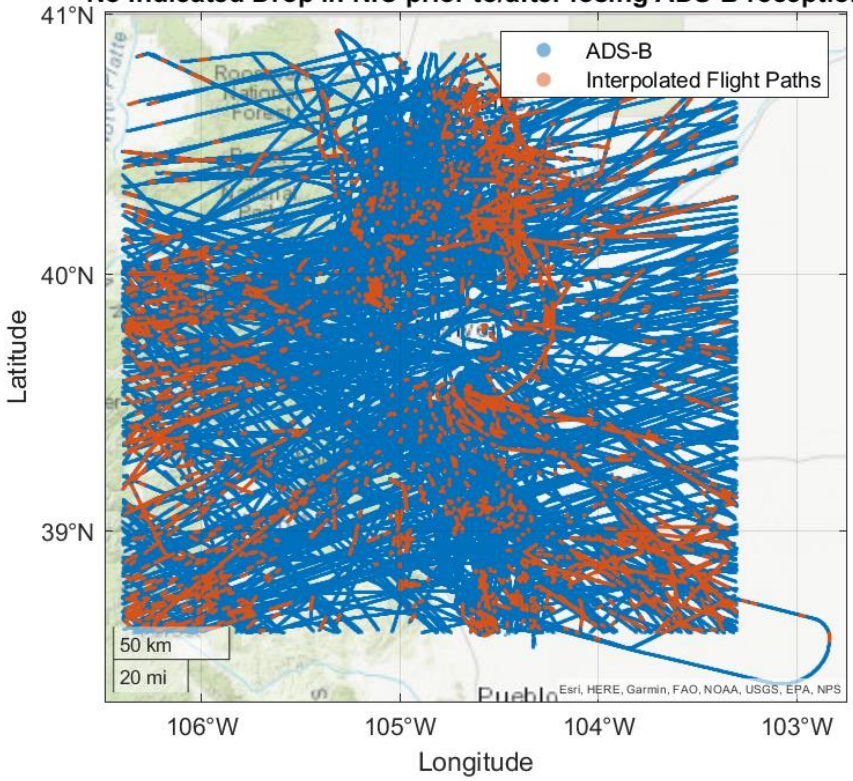
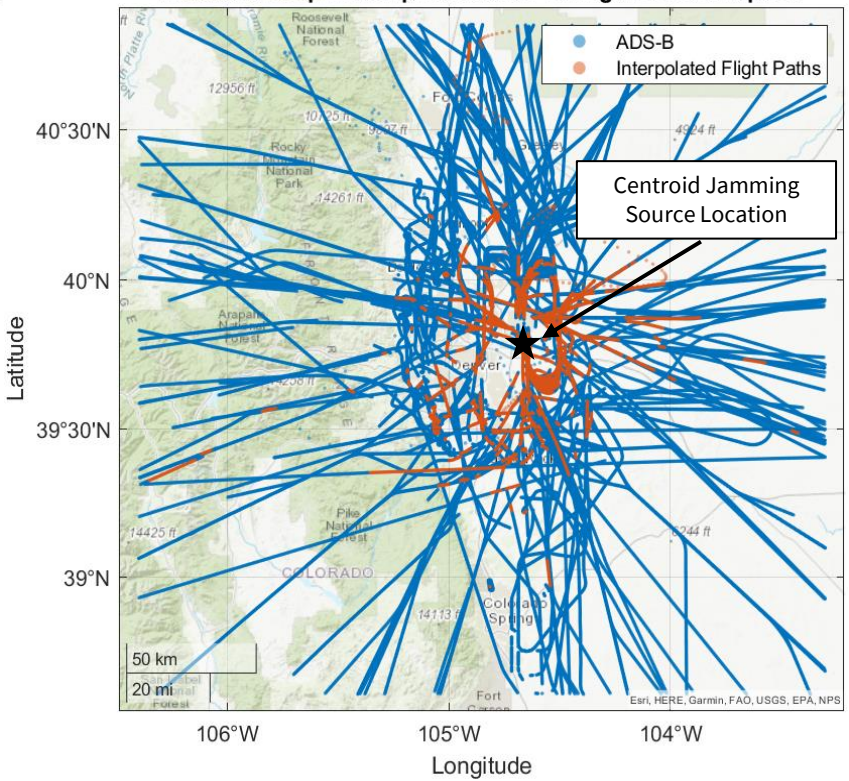
Interpolation and Localization Results

During Interference: Jan 22 (0700 UTC) – Jan 23 (0659 UTC) (2400 – 2359 Local Time)

No Indicated Drop in NIC prior to/after losing ADS-B reception



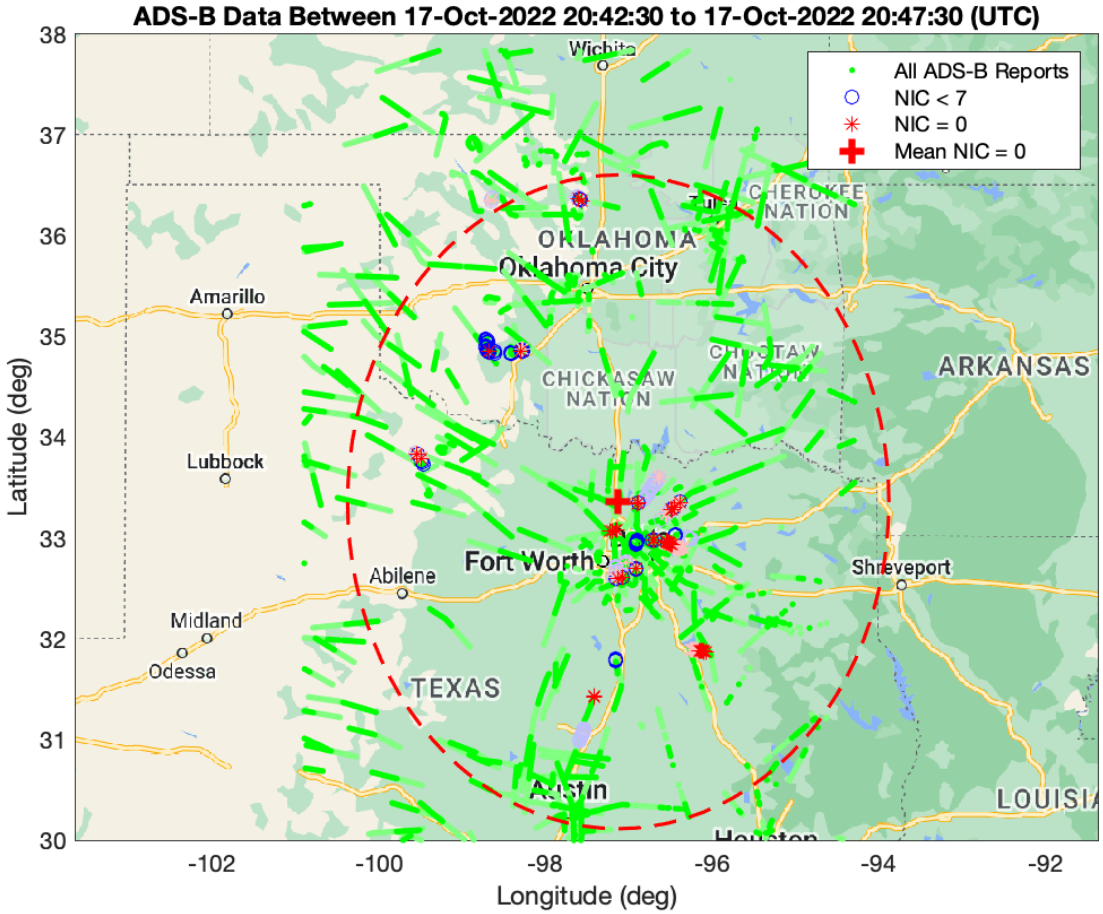
Indicated Drop in NIC prior to/after losing ADS-B reception



Interpolation Improvement to Flight Gap Dataset

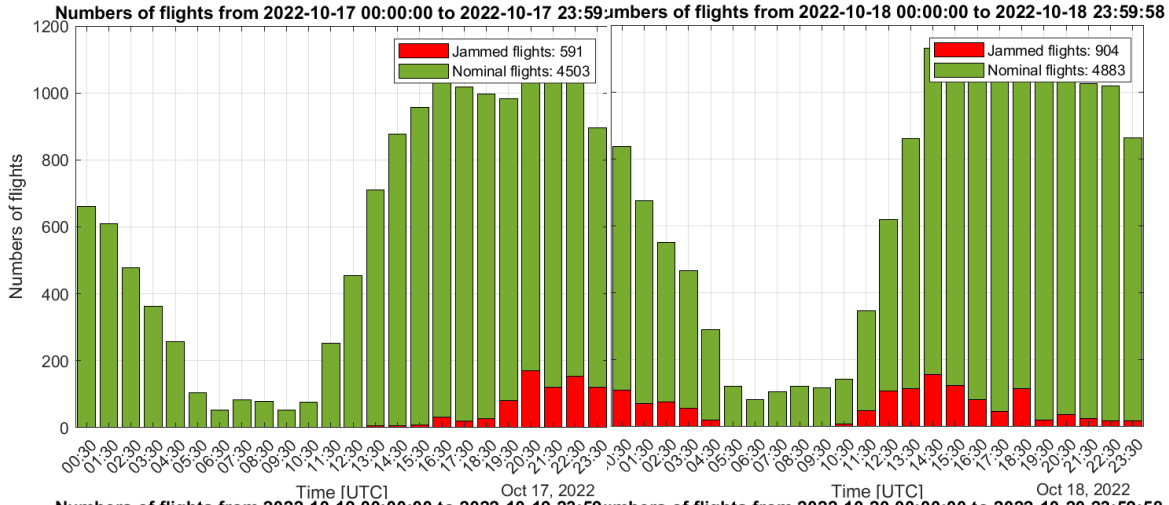
	Jan 21, 2100- Jan 22, 0659 UTC	Jan 22, 0700-Jan 23, 0659
Duration of ADS-B Data with NIC=0 [hr]	4.95	11.647
Data points added from Interpolation [hr]	2.22	4.45
Percent Increase of NIC=0 from Interpolated Data	44.69%	38.21%

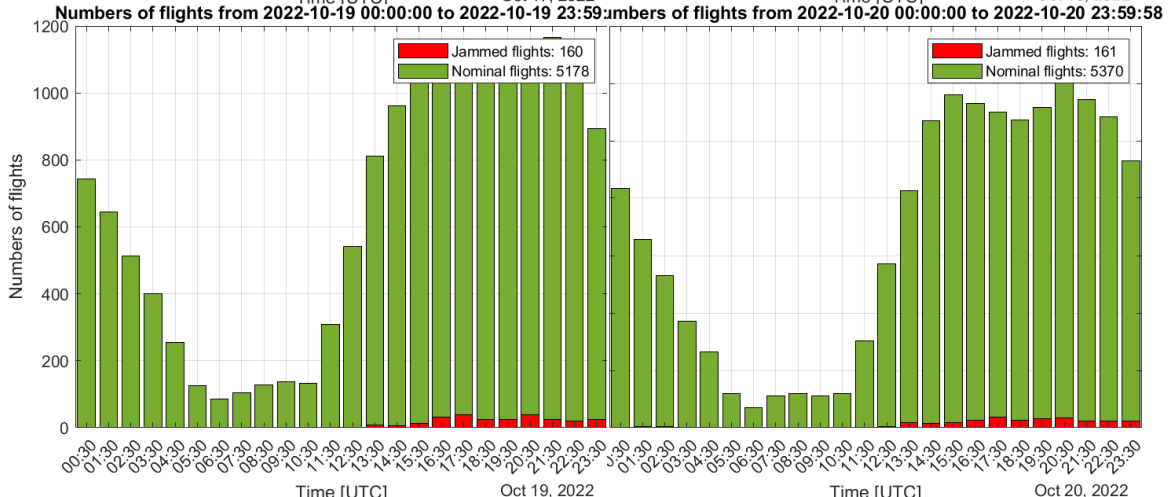
Dallas RFI Event October 17-20, 2022

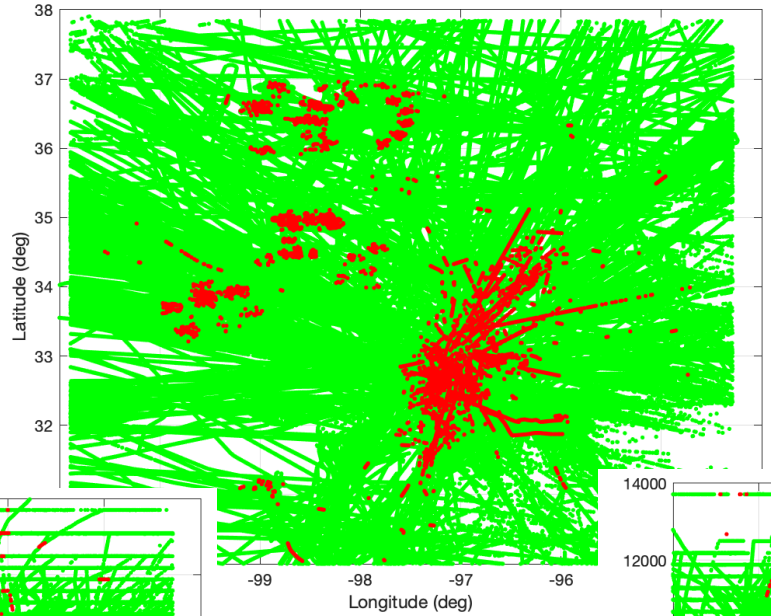


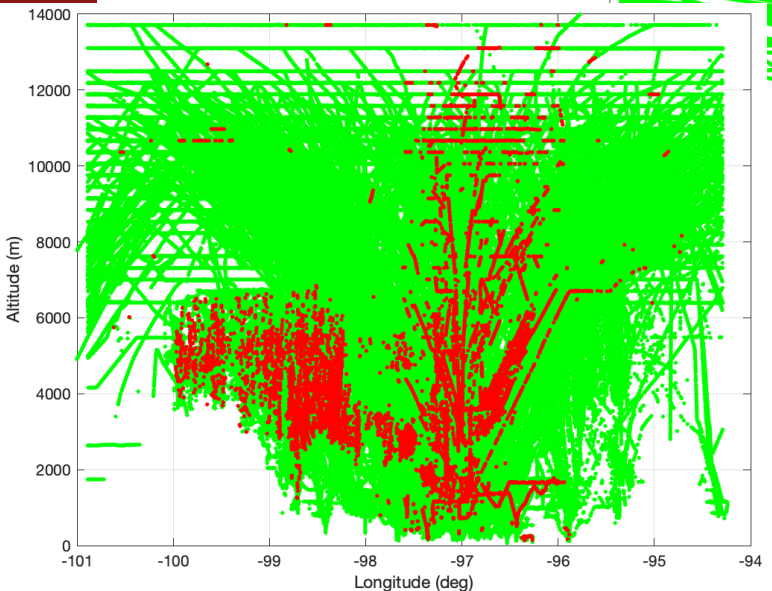
- Intermittent
- Initial start time: October 17, 2022, 19:21
- End time: October 20, 2022, 04:45
- Affected arrival and departure operations
- No significant reports of interference on the ground
- Origin unknown

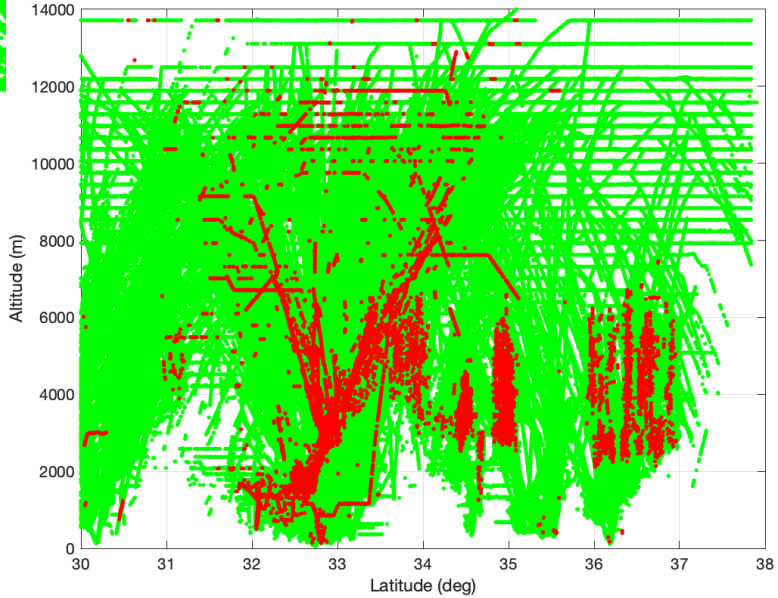
Number of Affected Aircraft vs. Total Aircraft in the Region



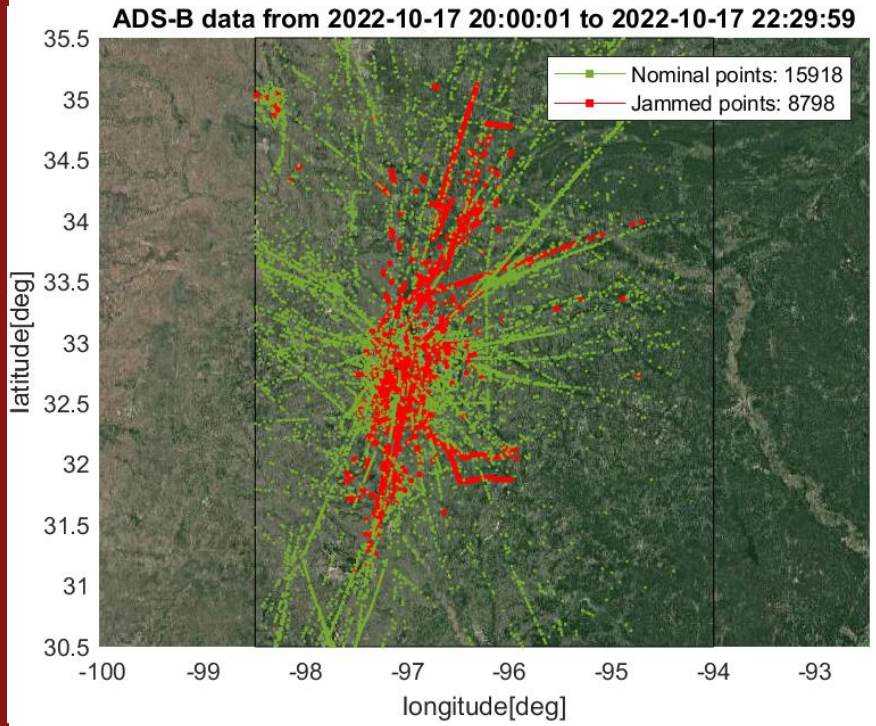


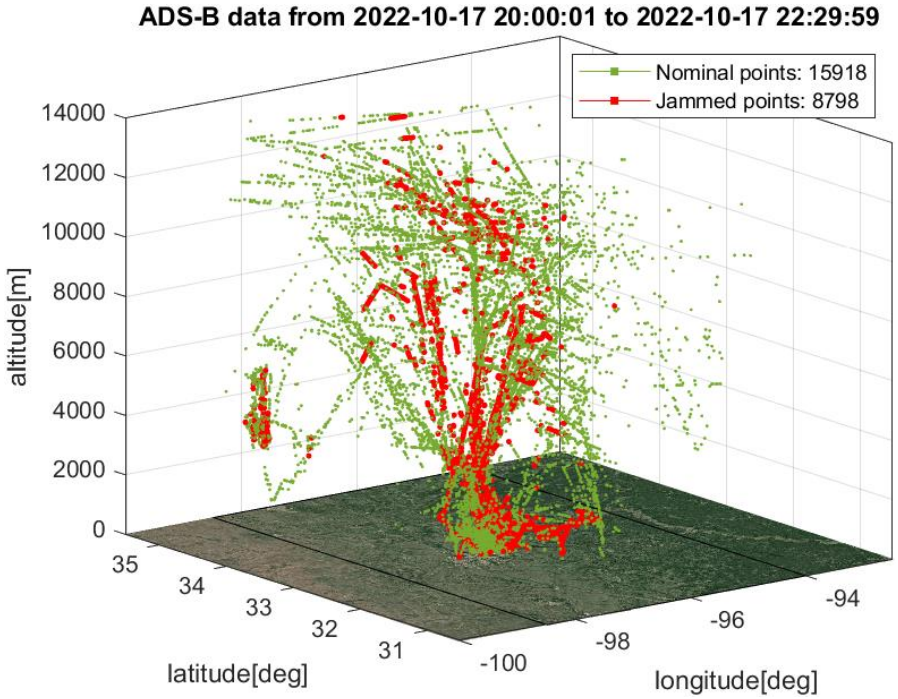

Latitude (deg)
38
37
36
35
34
33
32
-99
-98
-97
-96
Longitude (deg)


Altitude (m)
14000
12000
10000
8000
6000
4000
2000
0
-101
-100
-99
-98
-97
-96
-95
-94
Longitude (deg)


Altitude (m)
14000
12000
10000
8000
6000
4000
2000
0
30
31
32
33
34
35
36
37
38
Latitude (deg)

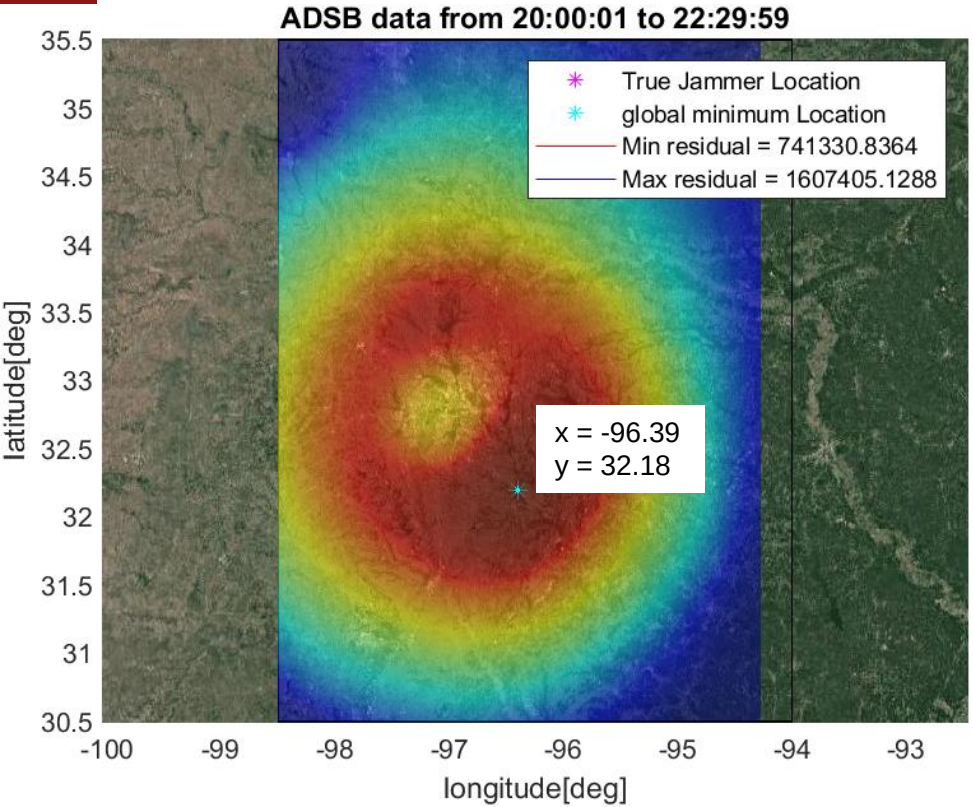
Flights with no NIC Changes Removed

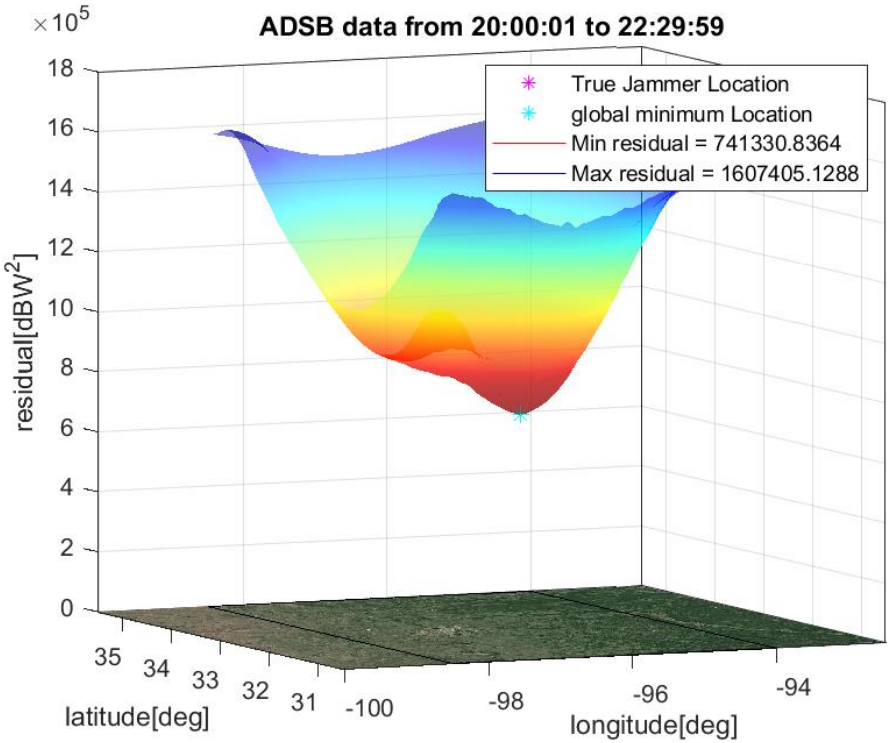




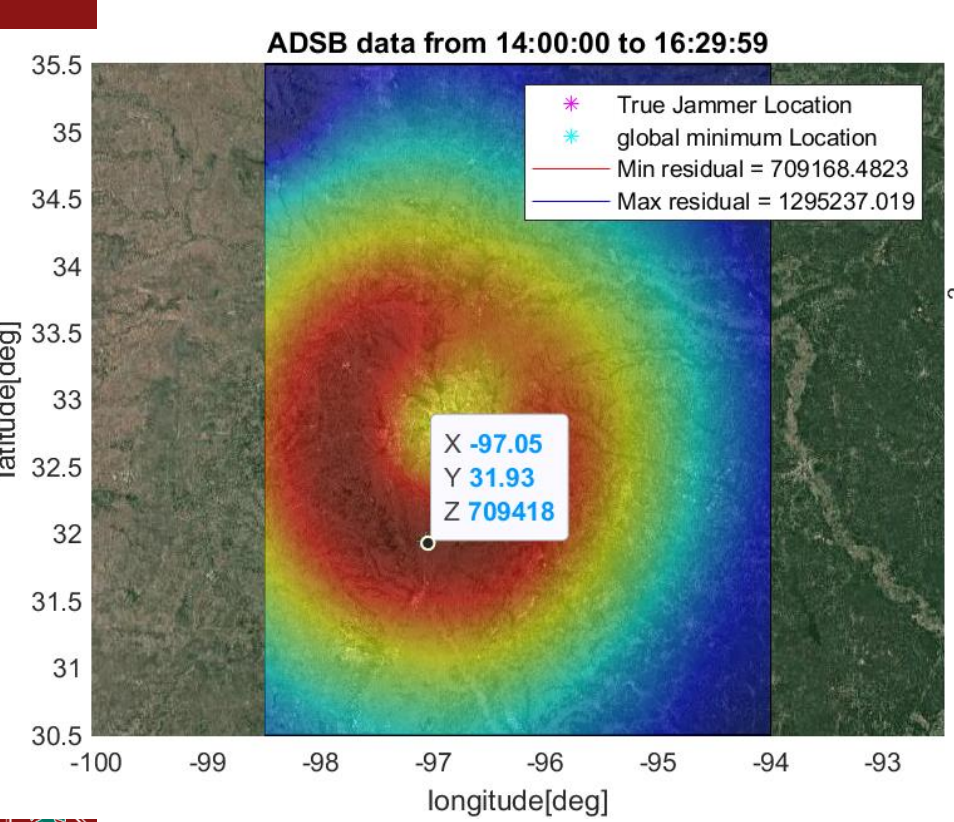
Some receivers show no impact due to interference despite close proximity to jammer (may be using inertial measurements)

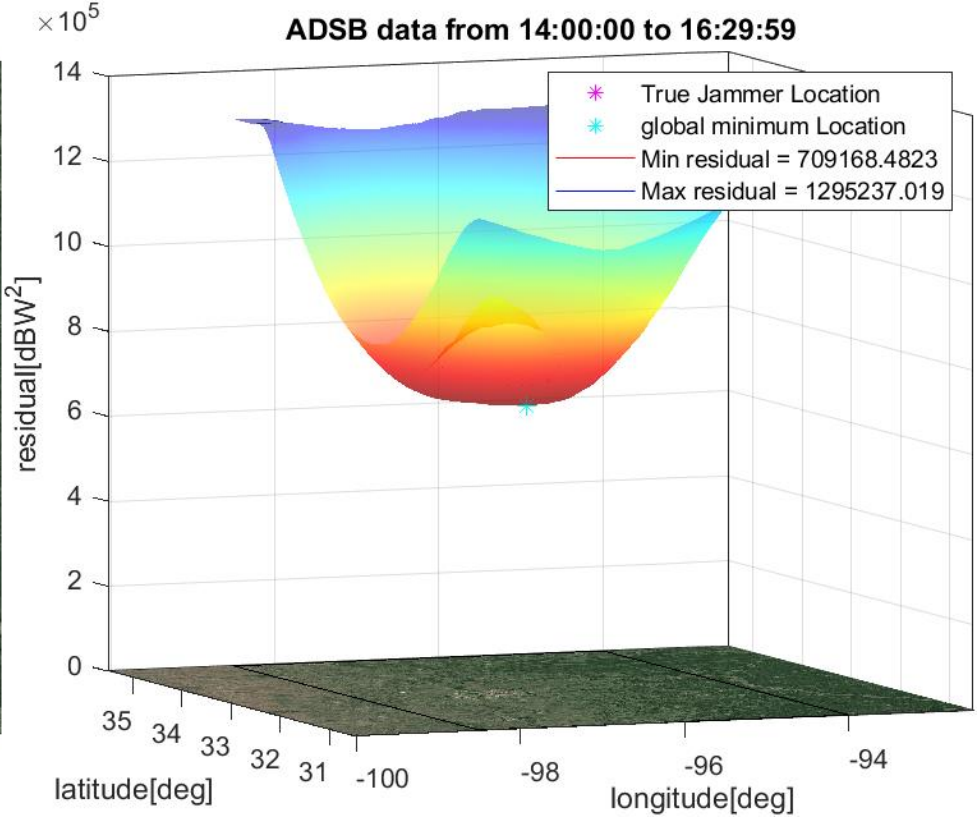
Location Estimate for Omnidirectional Antenna - October 17 20:00:00 to 22:30:00





Location Estimate for Omnidirectional Antenna – October 18 14:00:00 to 16:30:00



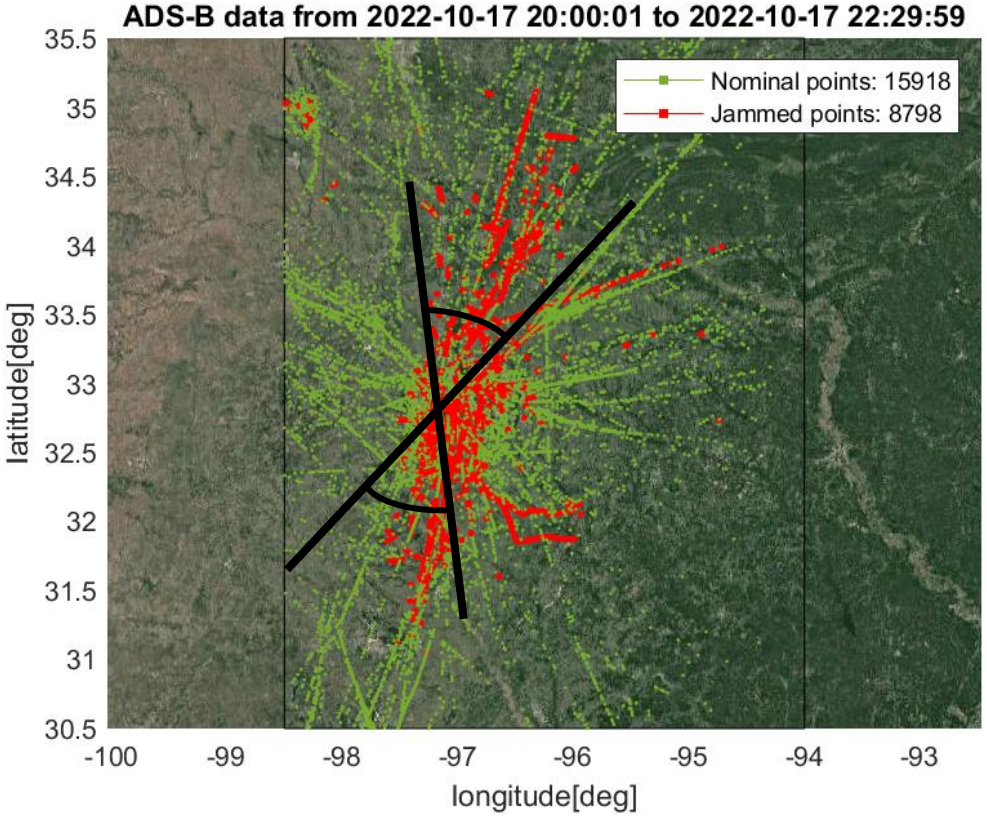


Directional Antenna

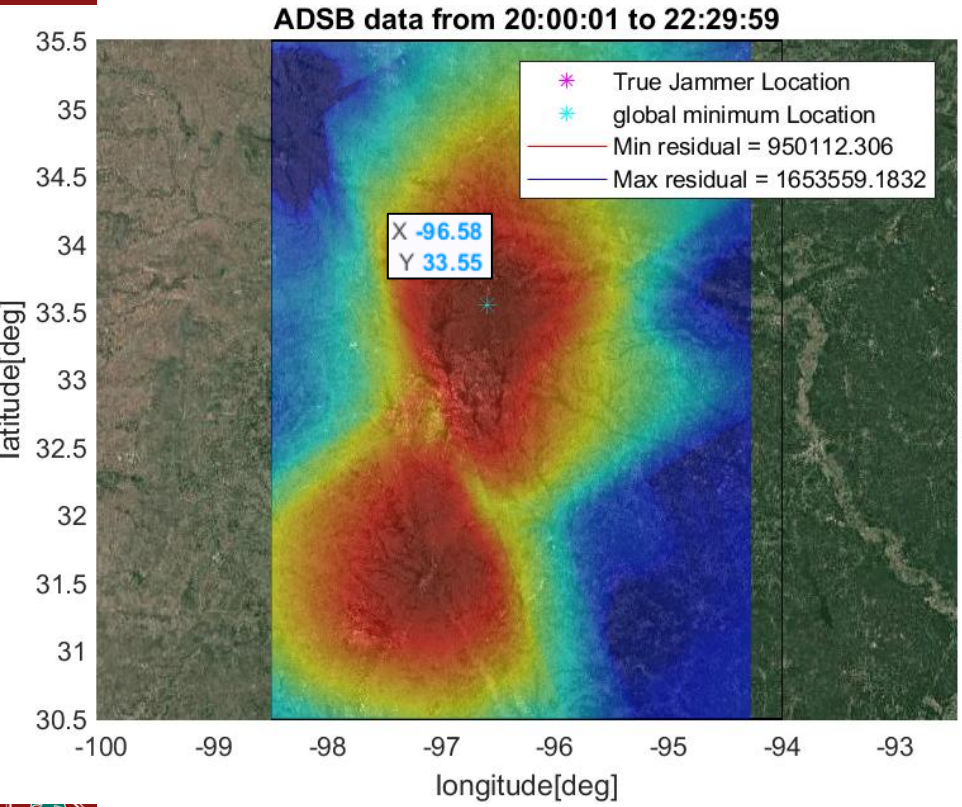
Angle of the line between aircraft and jammer, clockwise from North.

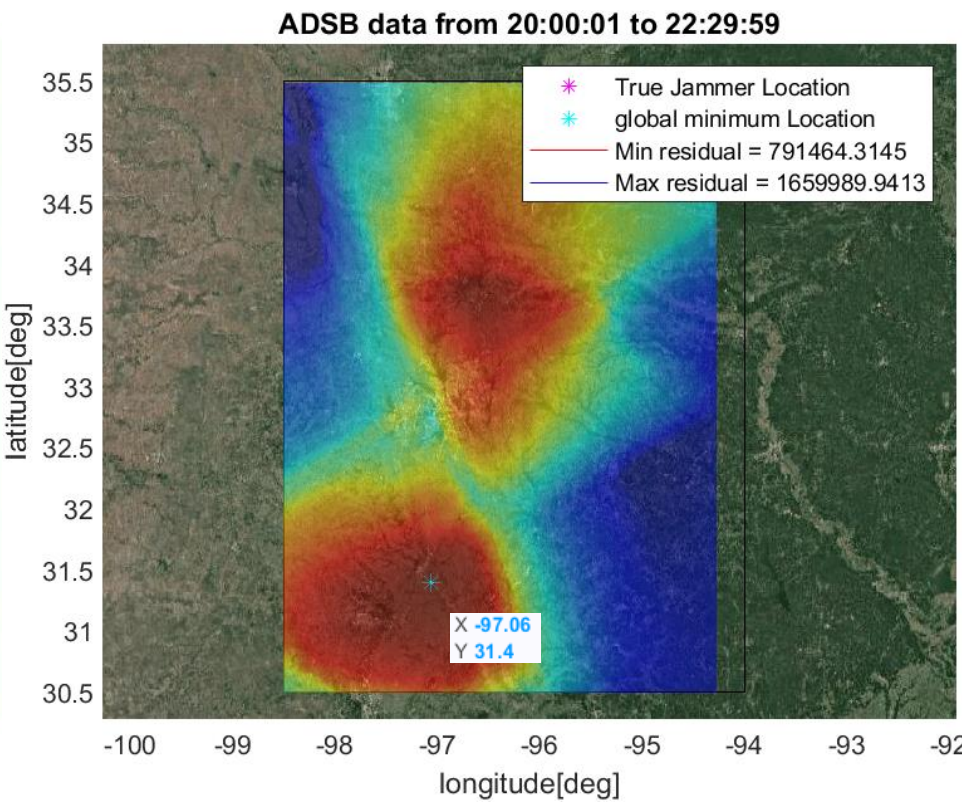
- (340°, 60°)
- (160°, 240°)

Mainly flights within these angles are affected.



Location Estimate for Directional Antenna - October 17 20:00:00 to 22:30:00





Summary

- ADS-B can be useful for identifying and localizing GNSS RFI
  - Estimation quite accurate for Denver event
- However, many challenges remain when processing the data
  - Missing data, poorly sampled regions, aircraft that may be relying on a non-GNSS source of determining position, erroneous positions, directional antennas, multiple jammers …
- Interpolation of position for data gaps associated with drops in NIC provides additional data that is very useful for improving the localization
- Evaluating two methods for localization
  - Least squares estimator
  - Bayesian estimator
  - Both provide accurate estimates for observed Denver event