Aireon Compatibility Analysis

Aeronautical Frequency Committee

3/10/2015

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Overview

- ADS-B Over Satellite Background
- Traffic Density and Interference Performance
- Introduction to ASIM and FRUIT Model
- UI Performance Results in a High Density Region
- Conclusions

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ADS-B Over Satellite Background

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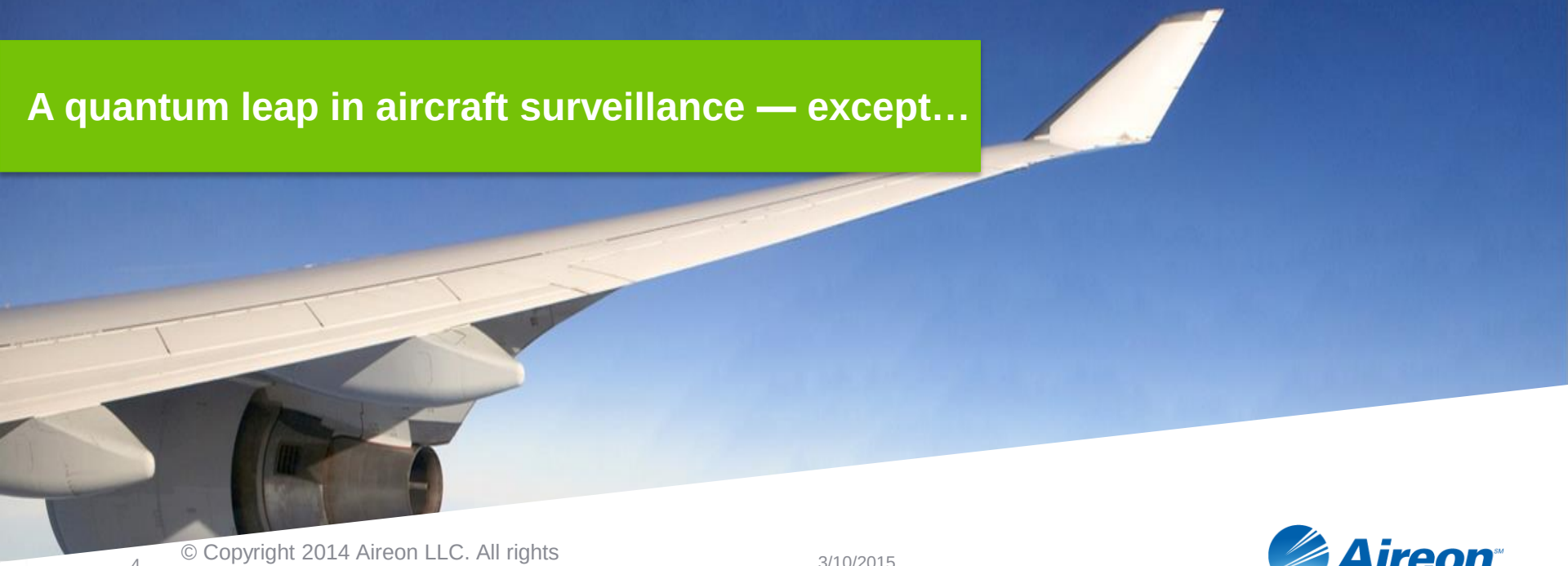
Automatic Dependent Surveillance – ADS-B (out)

- An innovative and proven surveillance concept through ground based stations
- Significant development in replacing or augmenting radar surveillance
- Upcoming transponder mandate for all aircraft in Europe and US
- Almost all new aircraft by default are ADS-B equipped



A quantum leap in aircraft surveillance — except…

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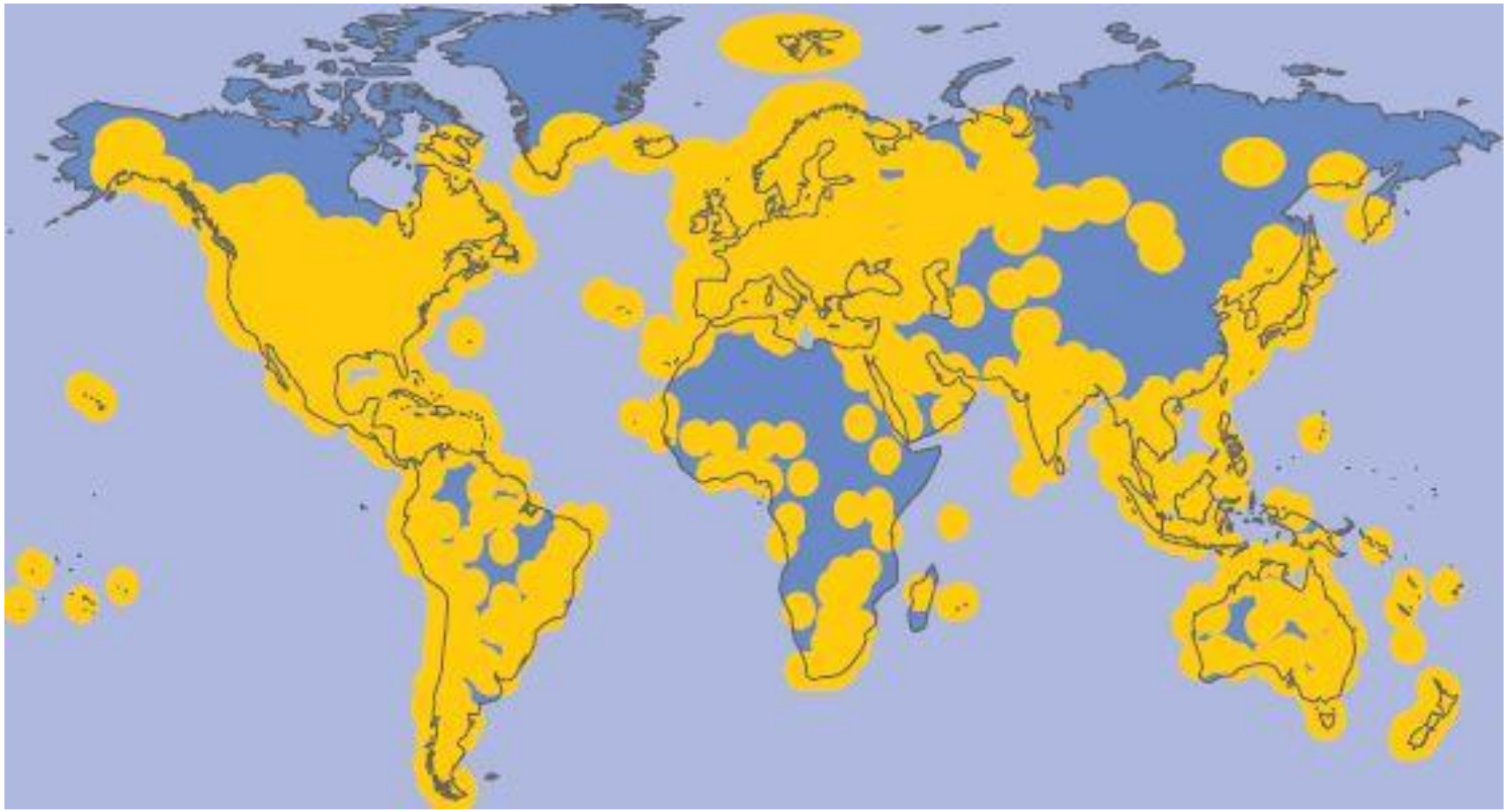
Significant Gaps in Surveillance Coverage Remain



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Why is Surveillance Coverage so Limited?

- Radars are expensive for low density airspace
- Radar and ground based ADS-B stations can be challenging to install in remote areas with high costs of maintenance and communications
- Limited ability to install facilities in the ocean or vast remote locations
- A majority of the world's airspace is uncovered by any real time surveillance
- Expanding the protection of 1090 MHz to space will merely introduce choice and help to remove geographical barriers to advance safety and efficiency in the world's aviation industry.

Global terrestrial surveillance is simply not feasible

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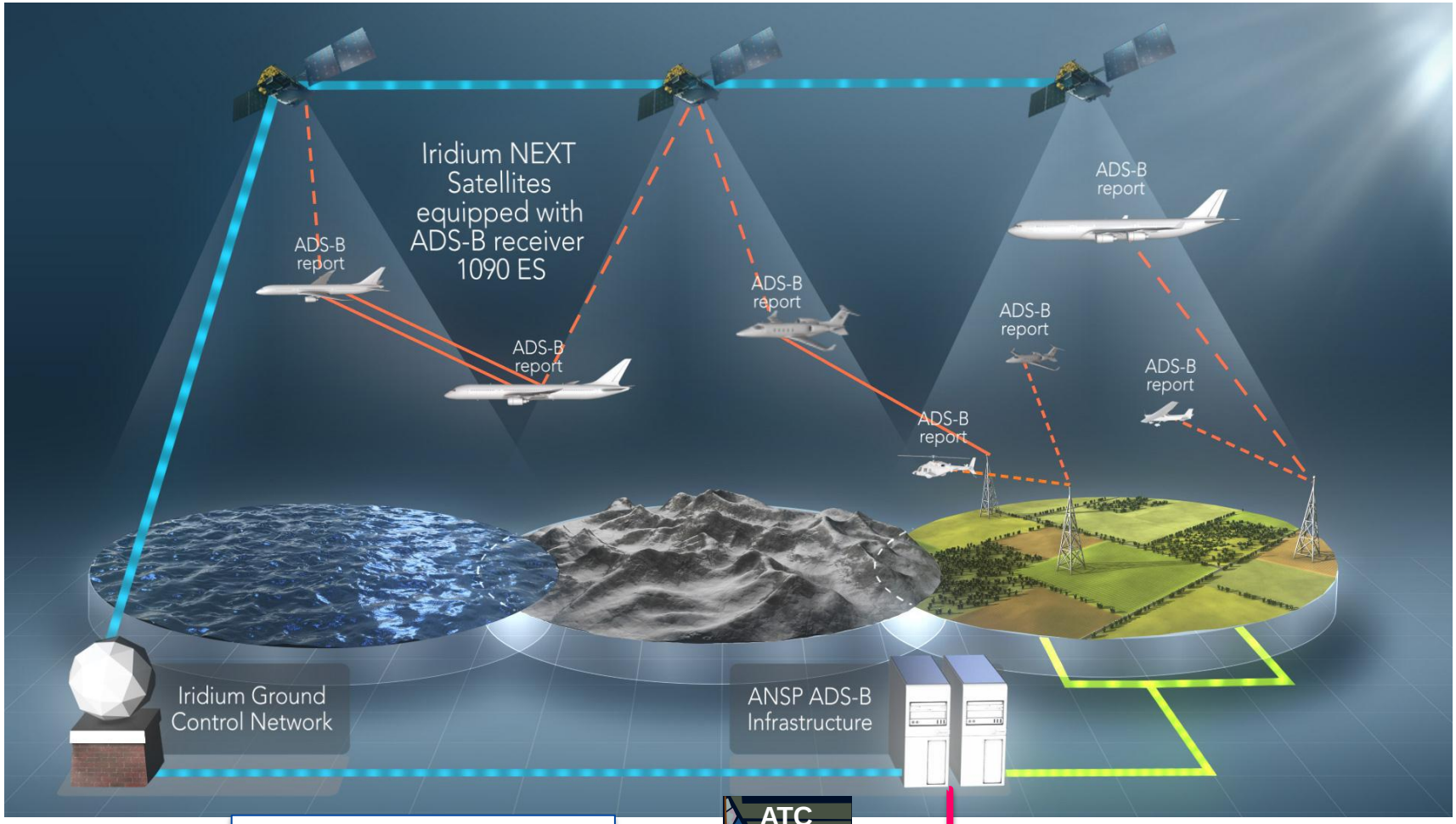
Aireon High Level Diagram



RTCA/EUROCAE Standard

DO-260B & ED-102A

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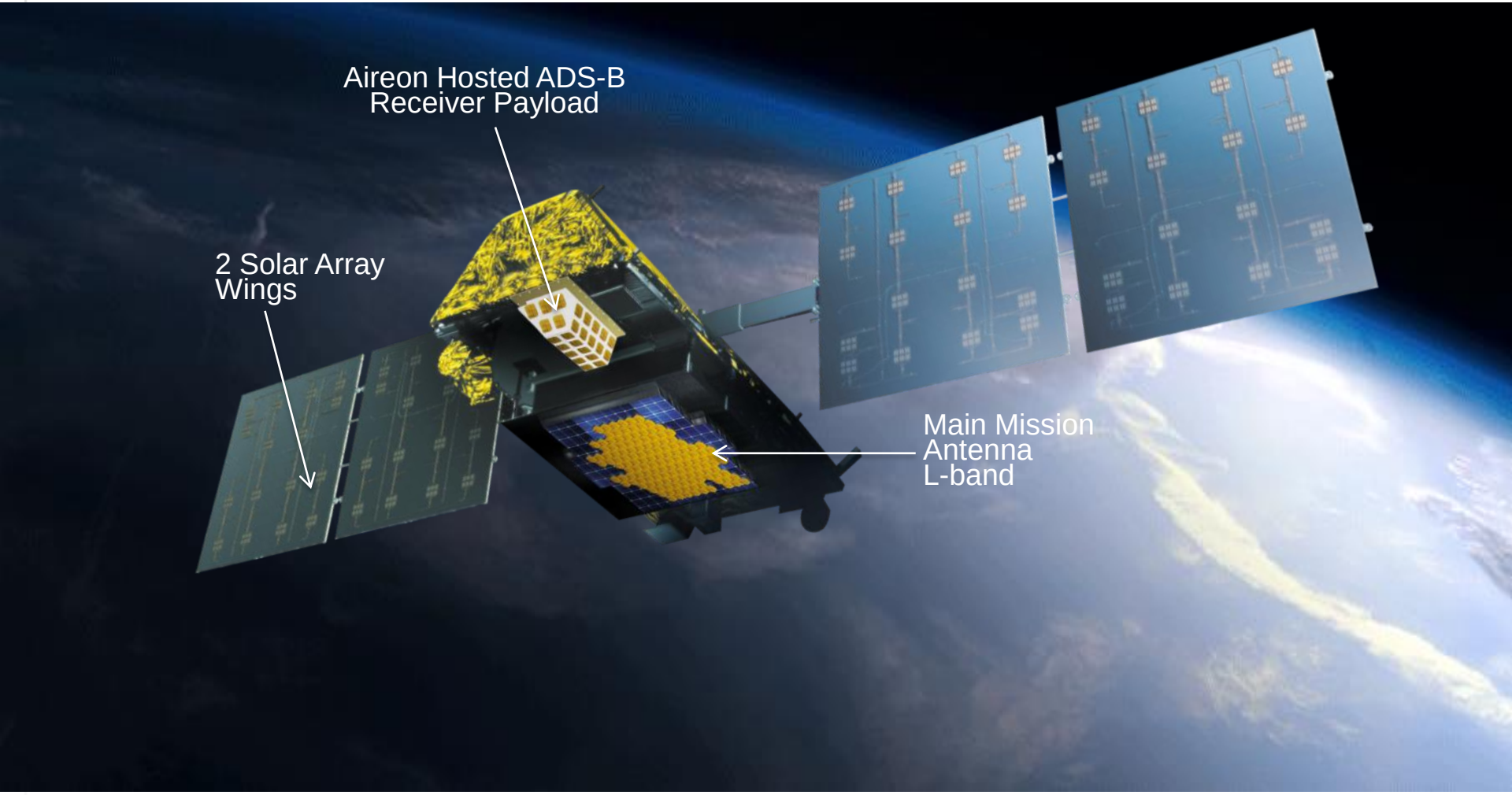
Launch in 2015, Global Coverage in 2017

- A $3 Billion US/Canadian/European satellite project, commissioned by Iridium, built by ThalesAlenia Space in France

- Space-qualified ADS-B receiver payload being developed by Harris Corporation will fly in a 72 LEO satellite constellation with 9 ground spares

- Systems engineering and ground data processing system by Exelis with significant expertise and existing ground based ADS-B infrastructure

Iridium NEXT Satellite Configuration



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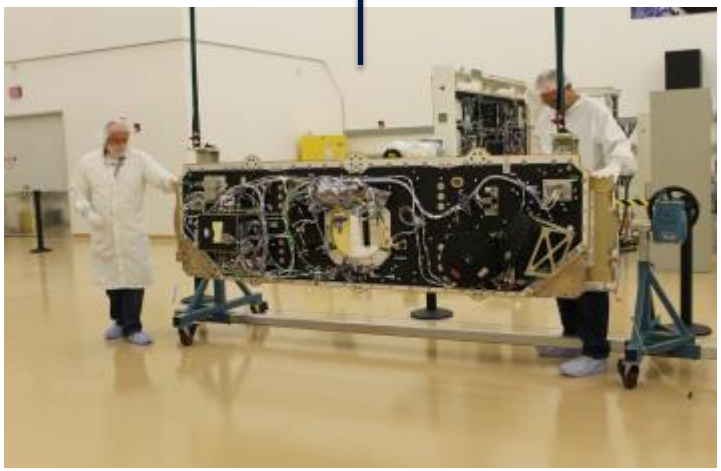
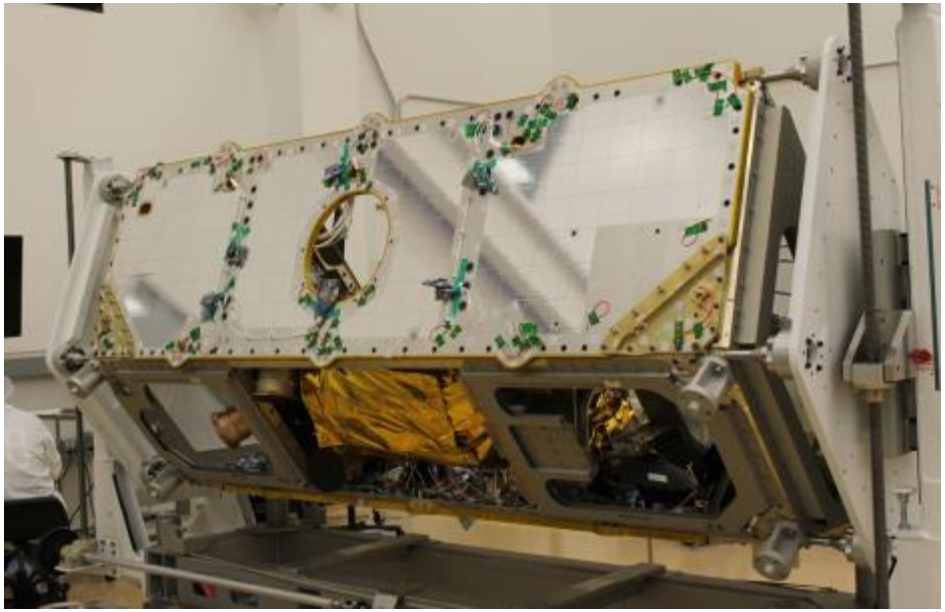
First Flight Satellites In Production





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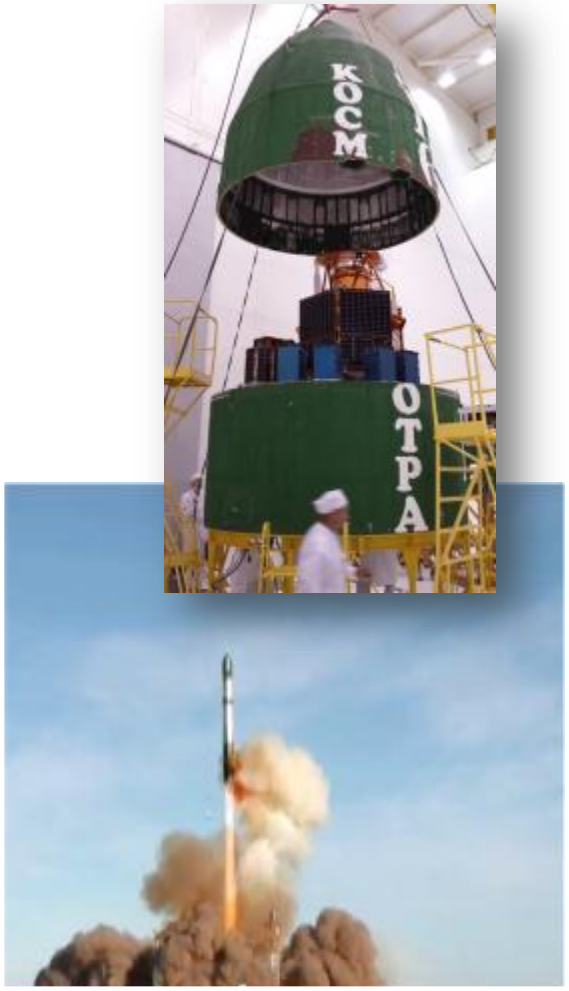
First Launch on a Dnepr (Kosmotras) in 2015

- Dnepr program
  - 37 Satellite Cluster – Successfully launched (June)
  - 2014/2015 Launch Manifest approval
- Iridium launch program
  - Qualification started in December 2014
  - Qualification Dispenser Testing Completed July 2014



Cluster Launch

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Remaining Launches on Falcon 9 (SpaceX)

- Falcon 9 Program
  - Successful Launch – August 6, 2014
  - Successful Launch – Sept 7, 2014
  - Successful Launch – Jan 10, 2015
  - Back-to-back Launches on 3 week centers!
  - Awarded 2-3 Heavy missions by Inmarsat
- Iridium Program
  - Successful Qualification of Iridium Dispenser
  - Dispenser Production Readiness Review – complete

Orbcomm1 Launch

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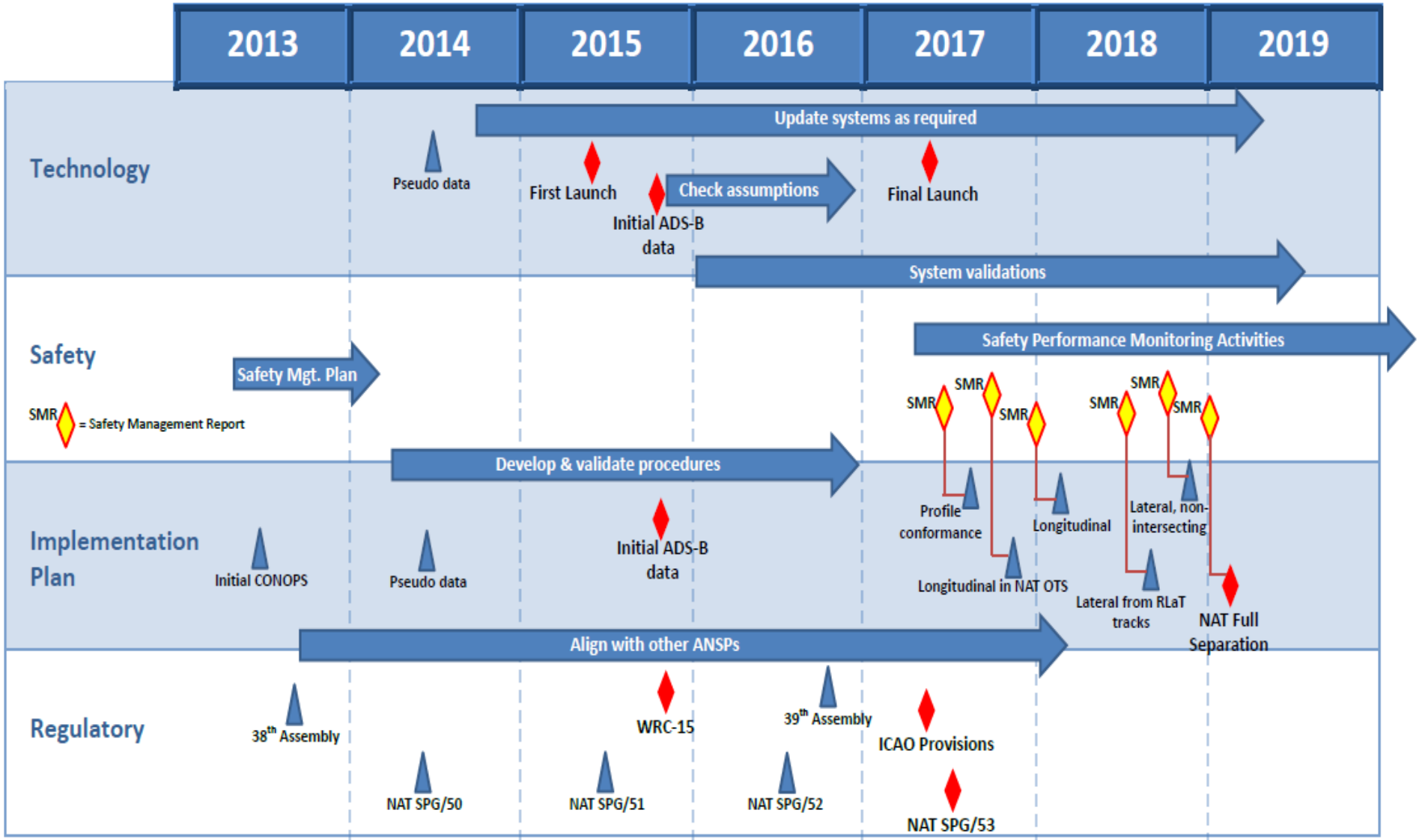
Ground Facilities involved with Aireon

Tightly integrated regulatory plan for 2018 CONOPS



FAA Agreement / Program Plan

- Memorandum of Agreement (MOA) between the FAA and Aireon for 2011 through 2014 is complete
- A new MOA was signed in October 2014 covering the period through FY2018 and will include the key activities of:
  - Design and development
  - Integration into the Surveillance and Broadcast Services system
  - Test and validation
  - Operational procedures development
  - Safety case development and international coordination
  - Integration with and modifications to the Advanced Technologies and Oceanic Procedures (ATOP) system
  - Business model development
- The FAA and Aireon will develop a Program Plan by Feb 2015 to achieve the following objectives:
  - Begin the necessary preparations to support enhanced separation services in FAA oceanic airspace using Space Based ADS-B
  - Protects the option for the FAA to begin using space-based ADS-B in 2018 consistent with the application of enhanced separation services by neighboring Air Navigation Service Providers (ANSPs)

Aireon proving to be a robust surveillance system

- Aireon System performance testing validates ability to support both reduced oceanic and terrestrial separation standards
  - Low Latency ≤ 2.5s to a ATC Surveillance Tracker
  - 95% of reports with Update Intervals ≤ 8 - 15 seconds, dependent on avionics transmit power and geographic latitude/location
- High availability design uses system redundancy and cross-linked communications backbone – 99.9% continuously global availability to the ICAO GOLD Standard
- System supports 125W ADS-B transponders with a top-mount/diversity antenna (almost all commercial aircraft are equipped with 200W or higher)
- Built to accommodate all existing and future ADS-B standards
  - DO-260B & ED-102A: Link Versions 0, 1, & 2
  - ED-129B (Pending Publication)
  - Eurocontrol ASTERIX and FAA Reports to ATC
- Capacity to handle future traffic growth

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Traffic Density and Interference Performance

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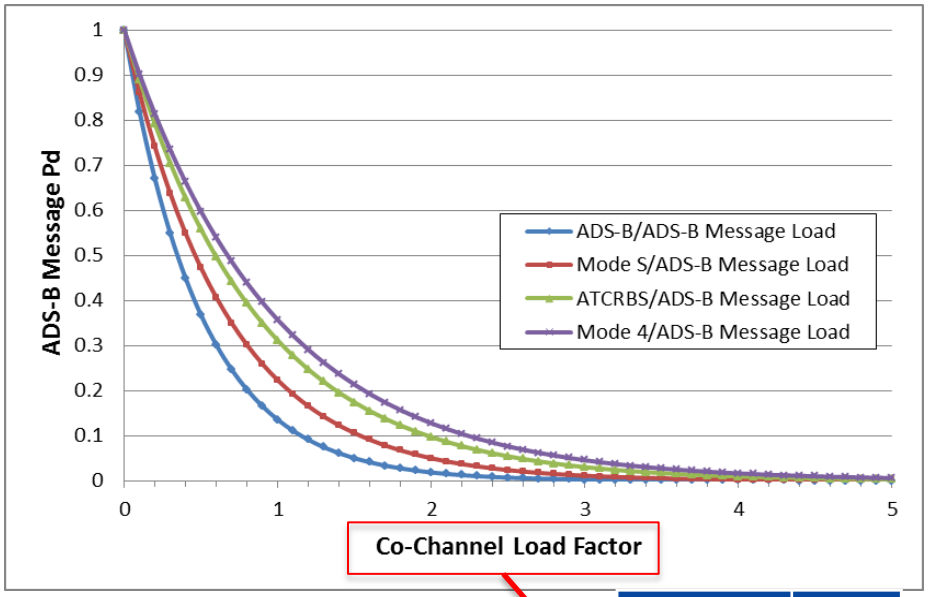
Performance Impact from Traffic Density - FRUIT

- Traffic density
  - Traffic density, both in and adjacent to Aireon coverage areas, has a potential impact on the Aireon System in two ways
    - The overall number of targets the system must support, i.e., target capacity
    - The effects of interference from the relatively high traffic density



$$P_{msg} = e^{-K*G}$$

Link	K
ADS-B	2
Mode S	1.5
ATCRBS	1.17
Mode 4	1.03

- False Replies Uncorrelated in Time (FRUIT)
  - High priority topic since beginning of the program
  - System Requirements based on FAA ADS-B Critical Services Specification

Multiple, independent analysis have demonstrated that the Aireon Hosted Payload provides significant FRUIT performance margin over the actual FRUIT environment likely to occur anywhere globally

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Evolution of FRUIT Analysis

- FRUIT was considered a high risk for detection of targets when located near the high FRUIT areas around the world.
- The initial design work on Aireon System was based on highly conservative and a simple FLAT FRUIT density model driven using STK
- This extensive analysis focused on worst case analysis of satellite and beams positions with respect to high density areas and concluded that the FRUIT's relative impact to the ADS-B aircraft of interest would be marginal, significantly less than our original FLAT FRUIT model specification
- Although the STK approach enabled snapshots of link margin and relative signal level analysis, it was difficult to extract the statistical effect to expected UI performance

This led to development of a custom tool for Aireon with a time-variant and spatially diverse FRUIT model with a stochastic design

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Introduction to ASIM and FRUIT Model

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Introduction to ASIM

- The Aireon SIMulator (ASIM) was developed by the Exelis APD team as a multi-use tool to support analysis for the APD CDR and the Performance Working Groups

- Incorporates an open source satellite tracking program and several customized modules that follow algorithms developed by the APD and the AHP

- ASIM's functions and capabilities have grown over time and is also being used for some initial market analysis and prototyping of new system requirements and features, such as:
  1. Recommending and Validating core algorithms within the APD system
  2. Provision configurable scenarios/data sets for APD test campaigns
  3. Assess the expected performance of the Aireon System

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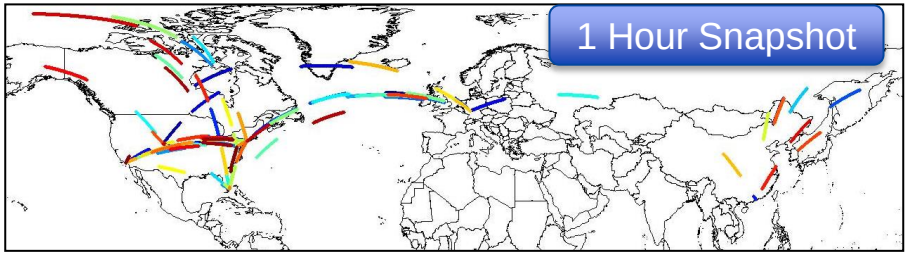
ASIM FRUIT Model



- Global FRUIT model has aircraft counts projected over each hour in each tile from FlightPlan data from 2013-07-05
  - ASIM converts aircraft counts to expected message rates with configurable assumptions relating to percentages of Mode S vs. ATCRBS, top vs. bottom squits, etc.
  - Current settings of these parameters are based on extensive FRUIT analysis of US Northeast
  - FRUIT Message Rates are dampened by Beam EbNo patterns over time in the Mission_Data_Filter application in order to account for lower vs. higher gain FRUIT interference impacts, resulting in effective FRUIT Message Rates

- Effective FRUIT Message Rates impact Pd
  - Using Poisson Arrival Rate approximation of prob of reception in the interference environment.
  - Method referenced from DOT/FAA Report ATC-214 "GPS-Squitter Capacity Analysis", 5/20/1994
  - Each Beam views the tiles with a different gain pattern, therefore ADS-B Aircraft viewed by multiple beams have a higher aggregate Pd

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Effect of Overlapping Messages on ADS-B

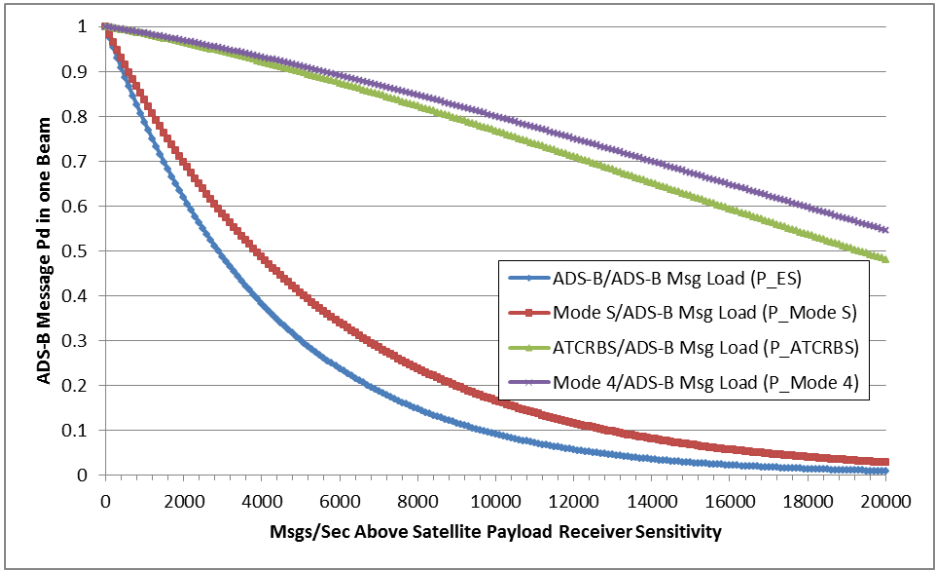
- 1090 MHz ADS-B is a random access channel link (i.e. ALOHA communication)
- Not all In-Band 1090 MHz messages affect ADS-B the same way
- ADS-B can tolerate some degree of overlap of shorter messages with enhanced decoding techniques described in DO-260B
- ATCRBS (Mode 1, 2, 3/A), Mode 4, and Mode 5
  - Have similar Message durations (~20 us)
  - Have reply rates ≤ terrestrial ATCRBS to cooperative surveillance systems
  - Therefore these are all grouped together as ATCRBS in this FRUIT Model
- JTIDS signals are ≥ 22 MHz from 1090 MHz and are therefore considered part of the Gaussian noise environment (out-of-band)
- TACAN/DME transmissions/replies are typically at least ≥ 5 MHz from 1090 MHz, have a low duration (~3.5us) and a low reply rate

For ATCRBS, up to 3 overlaps

$$P_{\text{ATCRBS}}(R \mid n) = \begin{Bmatrix} P_R & n=0 \\ 0.89P_R & n=1 \\ 0.64P_R & n=2 \\ 0.52P_R & n=3 \\ 0 & n>3 \end{Bmatrix}$$

For Mode S, no overlaps

$$P_{\text{ModeS/ES}}(R \mid n) = \begin{Bmatrix} P_R & n=0 \\ 0 & n>0 \end{Bmatrix}$$



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FRUIT Model Assumptions
Aircraft Counts to Message Rates to Pd

Aircraft Count Per Tile per Hour of Day

→

Tx Message Rate per Tile per Hour of Day. Categorized by Link Tech, Tx Power, and Top/Bottom Antenna

→

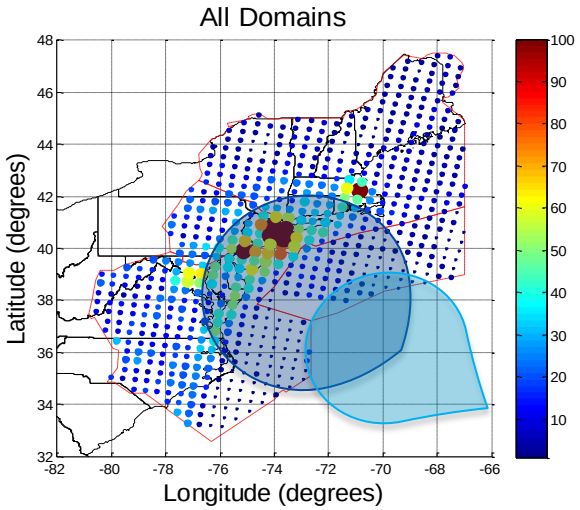
Mission Data Filter Applies Beam Gain Coverage over custom Traffic and associated FRUIT environment

↓

Rx MER curve used to estimate FRUIT impact, resulting in effective Rx Msg Rates for each type

→

Rx Msg Rates for each type input into Poisson Arrival Rate model for impact to Clear Sky Pd



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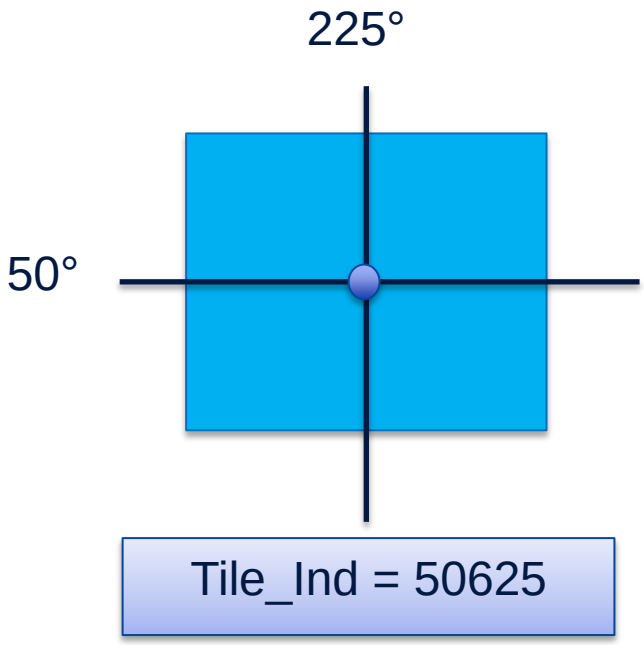
Tile Index Calculation

- APD and ASIM Divide the World up into 1 degree x 1 degree Tiles
- Service Volume Tiles
  - Tile Index Calculations
    - Tile_Ind = ((90 + Tile_Lat)*360) + Tile_Lon
    - Tile_Lat = floor(Tile_Ind/360 – 90)
    - Tile_Lon = Tile_Ind - ((90 + Tile_Lat)*360)



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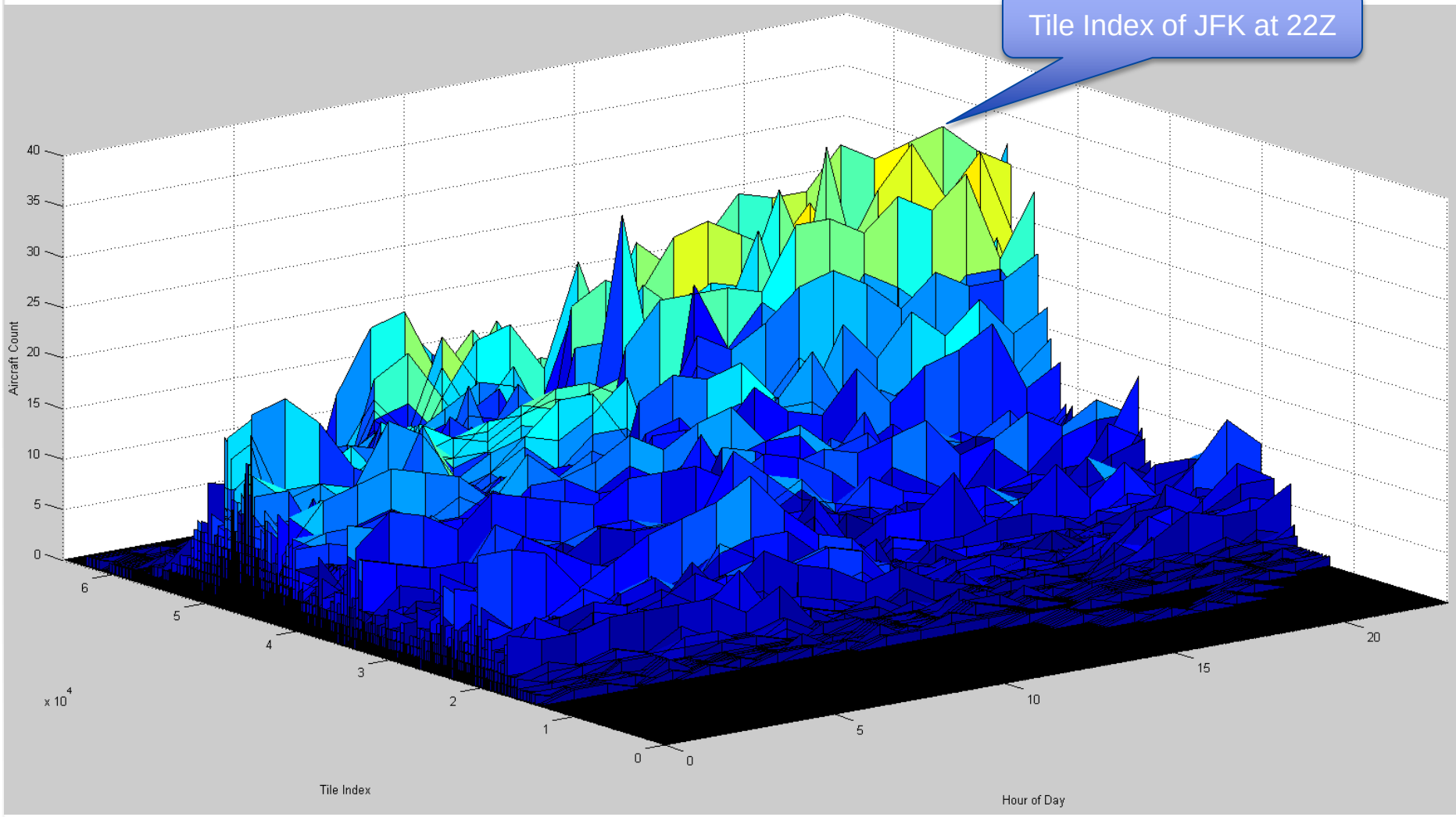
ASIM FRUIT Model Aircraft Count



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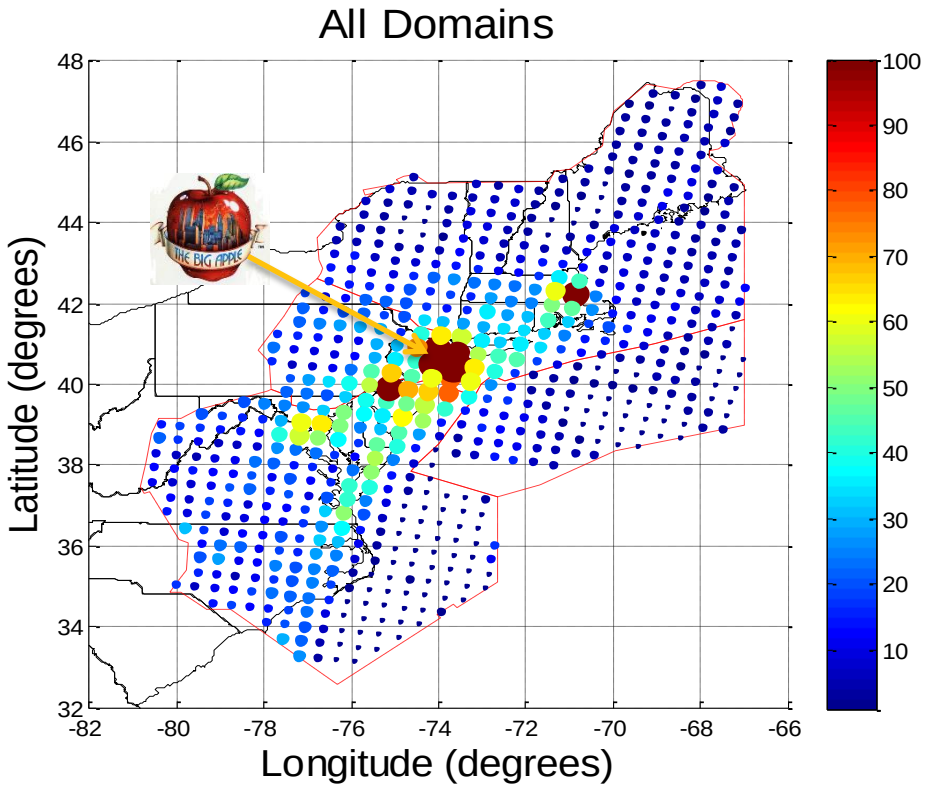
Comparison with ADS-B Flow Control Aircraft Density

- Used 10 days of recorded US Northeast Area Target Data to create a 3D histogram
- Normalized orthogonal density



[1] Garcia, M.A., J. Keller, J. Boughton. (2013). “ADS-B System Network Bandwidth and CPU Optimization”. IEEE/Syscon 2013

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FRUIT Model Assumptions
Aircraft Counts to Message Rates to Pd

Parameter	Value
Fraction Mode S	0.9
Fraction of Mode S that has ADS-B	0.3
ADS-B msgs/s/aircraft	6
Mode S msgs/s/aircraft	4
ATCRBS msgs/s/aircraft	60
ADS-B Fraction of Top transmissions	0.5
Mode S Fraction of Top transmissions	0.5
ATCRBS Fraction of Top transmissions	0

Link Tech	125W	250W	500W
ADS-B	0.25	0.5	0.25
Mode S	0.54	0.3	0.16
ATCRBS	1	0	0

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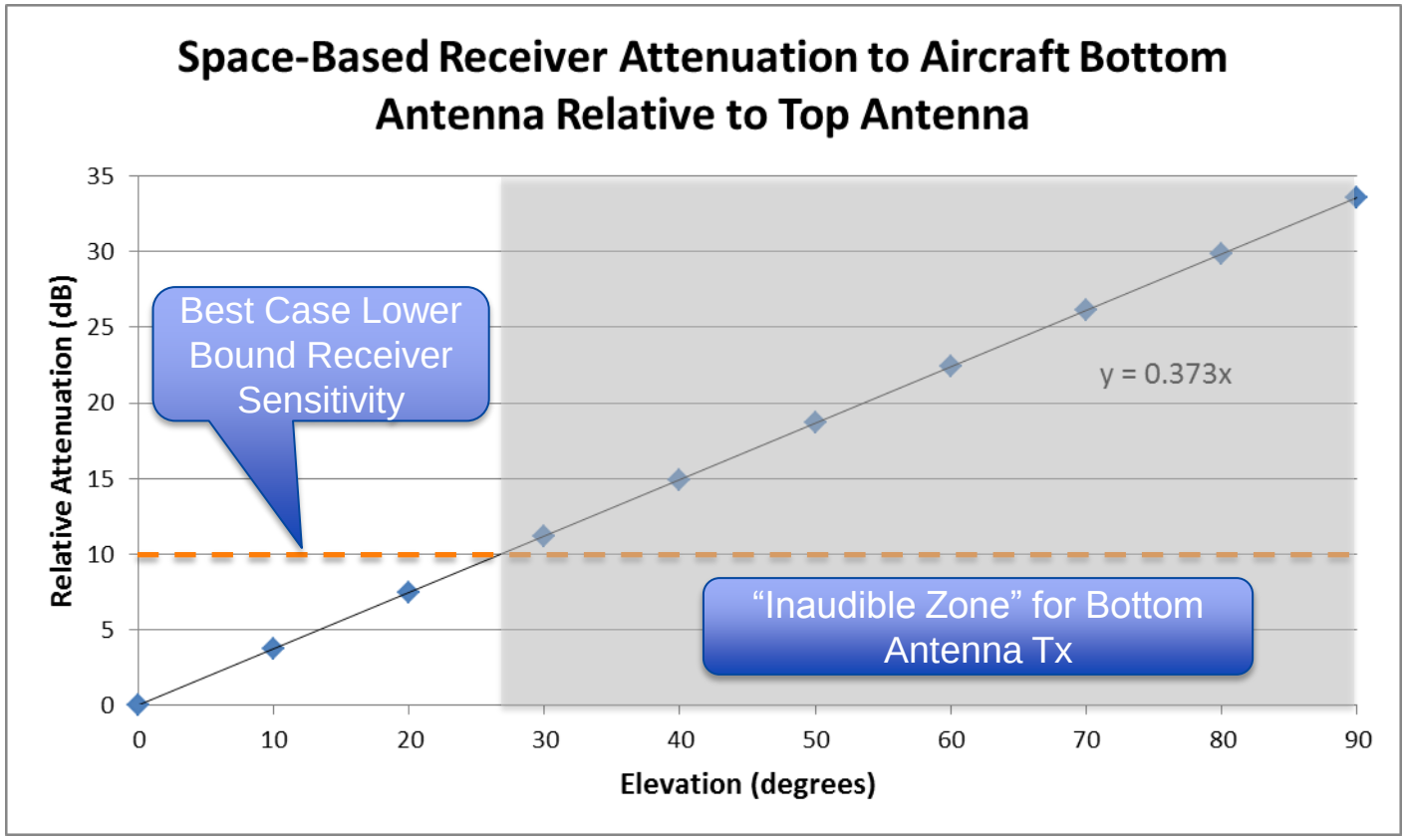
Effect of Aircraft's Bottom Antenna Tx on Reception of Top Antenna ADS-B Tx



This attenuation relative to the bottom antenna significantly reduces the impact of the majority of FRUIT replies to terrestrial interrogations

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UI Performance Results in a High Density Region

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Evaluation of Space-Based ADS-B Compatibility with 1090 MHz In-Band Systems

- Compatibility is Subjective and Depends on the Mission
- Aireon's Core Mission
  - Probability of achieving an UI of 15s is ≥ 95% in low density/oceanic airspace
    - For ADS-B Aircraft with Transmit Power ≥ 125W and a top mounted antenna
- With the proper communications, safety case, and procedures
  - This UI performance to ATC could support aircraft separation ≤ 10 NM
- Although any and every point on the earth could be evaluated for "compatibility"…
  - The test aircraft in the ASIM simulation were placed in oceanic/low-density airspace most proximate to the 20 busiest airports in the world

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Method for Determining Top 20 Highest Density Tiles

- Wikipedia Page Shows Busiest Airports by Number Aircraft Movements during 2011
  - http://en.wikipedia.org/wiki/World's_busiest_airports_by_aircraft_movements
- Catalogued Top 20 airports and determined their coordinates
- Added SEQM in Ecuador as a busy airport near the equator
- Calculated distance between all Low Density FIRs and each of the airport coordinates
  - Found the Tile in Low Density FIRs with the minimum distance to each respective airport
- Aggregated List of “Hot Tiles” and consolidated to 17
  - 46008 came up as a result as nearest to Philadelphia (same as Power Analysis)
  - 3 Tiles came up multiple times near Chicago, Las Vegas, and Heathrow
- Placed aircraft with each Tx power type (low, med, high) at each Hot Tile, all equipped with NI50 antenna

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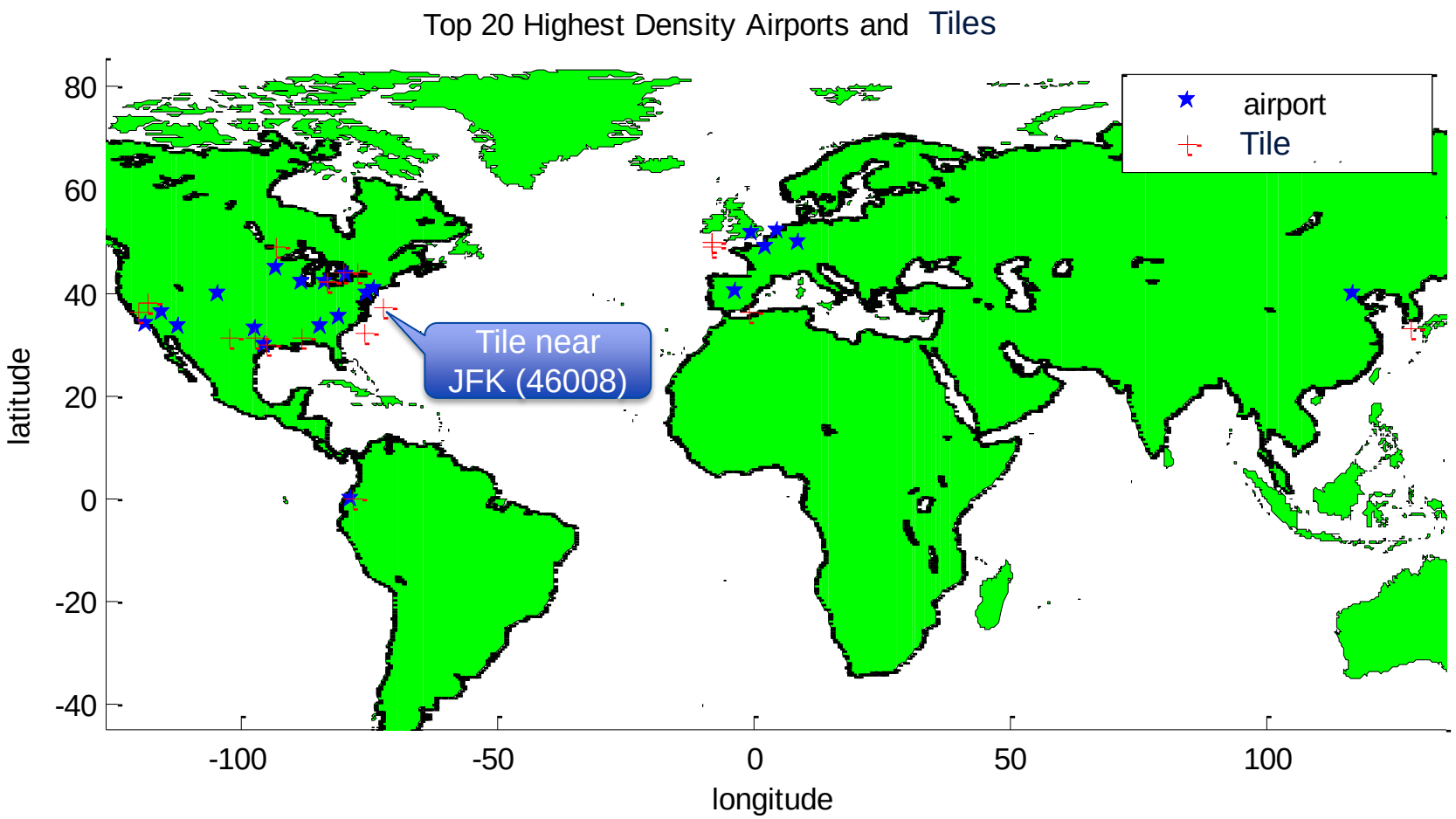
Top 20 Highest Density Airports and Nearest Tiles in Low Density FIRs



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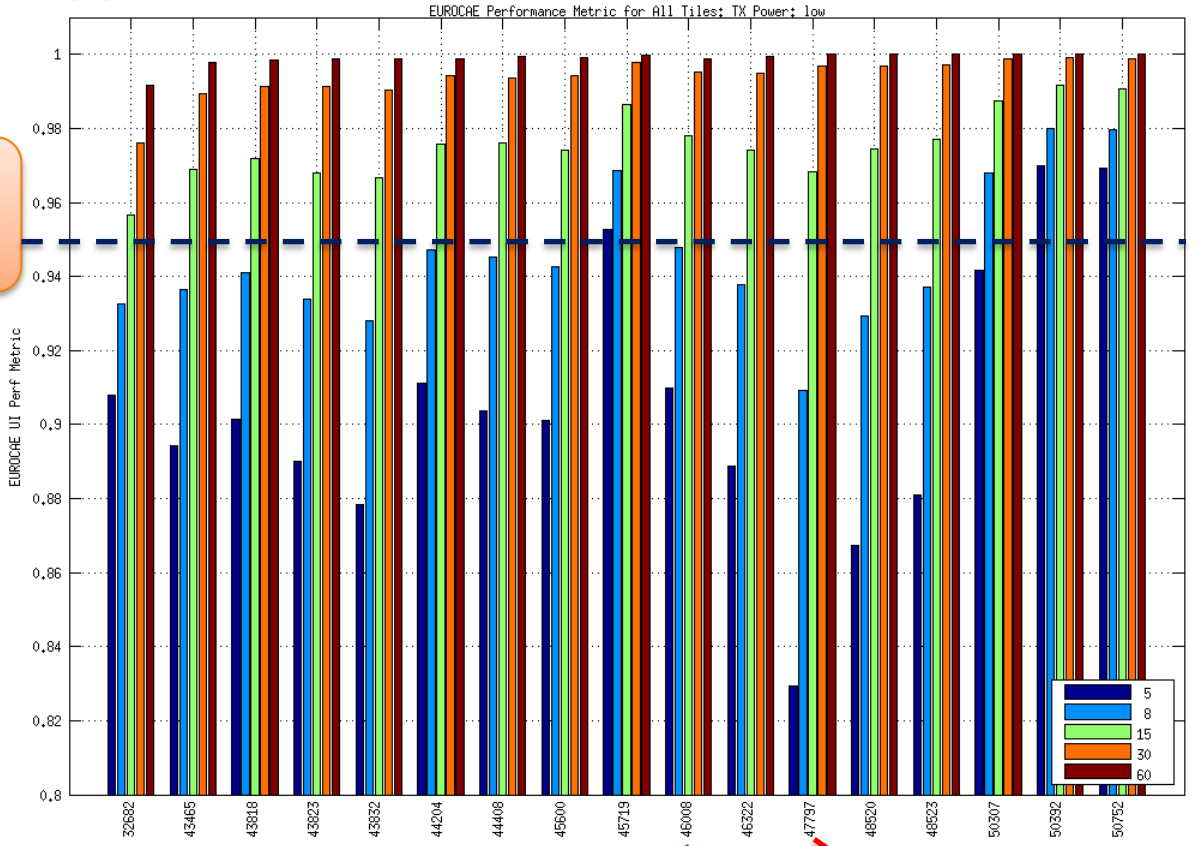
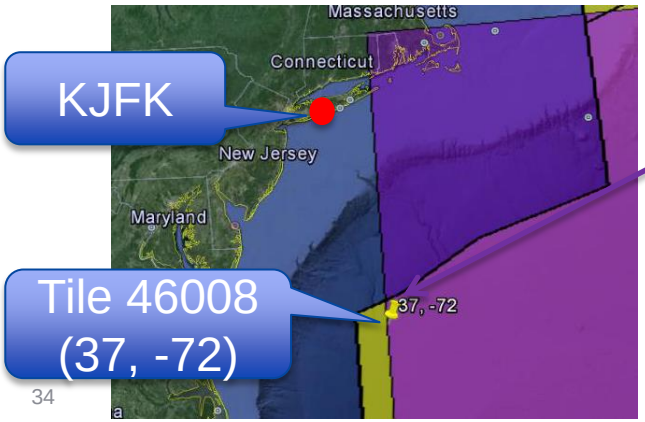
ADS-B UI results for **125W** Aircraft in the Top 17 High Density Tiles

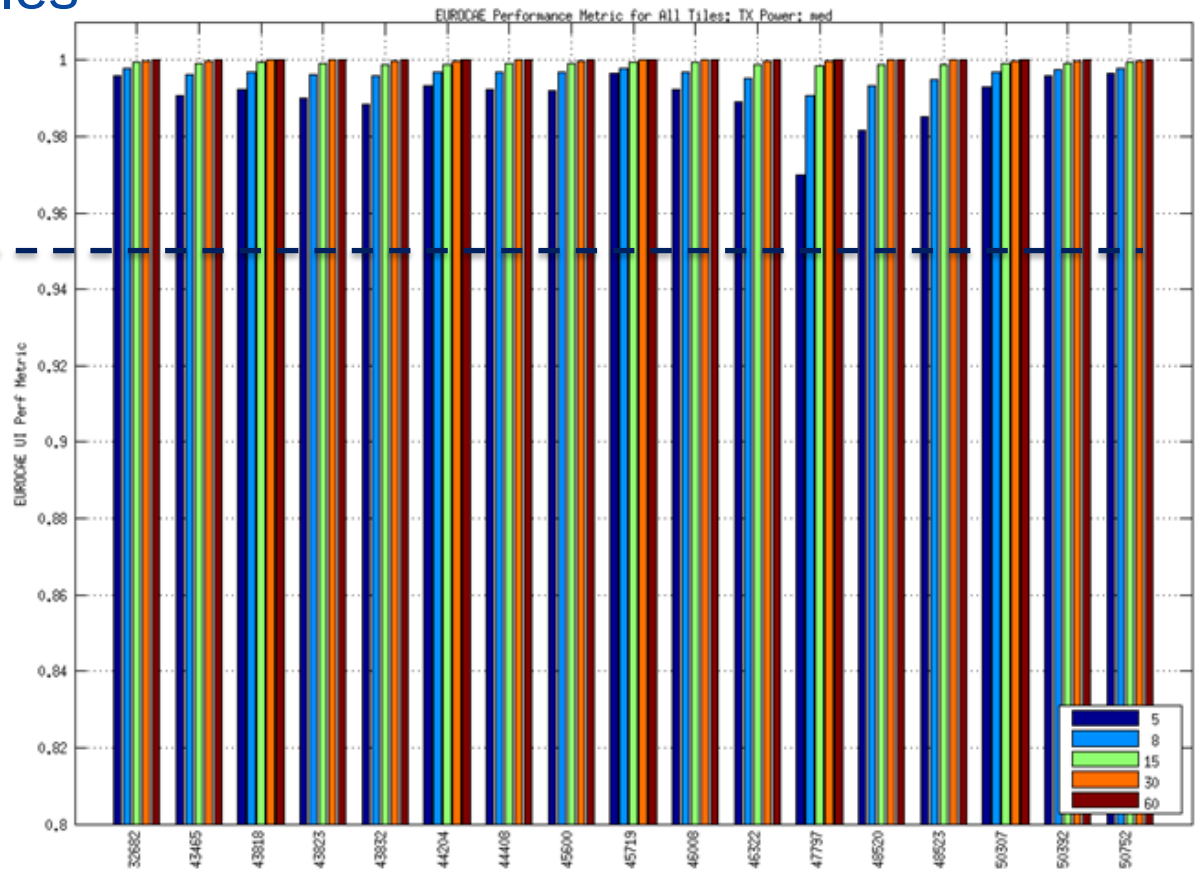
15s UI ≥ 95% achieved in all 17 evaluated tiles





ADS-B UI results for **250W** Aircraft in the Top 17 High Density Tiles

5s UI ≥ 95% achieved in all 17 evaluated tiles



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Aireon Compatibility Analysis Conclusions

- This presentation describes Aireon's stochastic 1090 MHz ADS-B co-channel interference model and simulation of its performance
- This model has been reviewed and refined extensively over the last 14 months with NAV Canada, IAA, NAVIAIR, ENAV, NATS, and the FAA.
- The assumptions within this model are generally conservative, but will need validation/calibration upon launch and initial data captures
- Compatibility of Aireon with current in-band surveillance and other ARNS systems has been analytically demonstrated
- Co-Primary allocation in ITU for aircraft to Space-Based ADS-B receivers would impose no additional in-band or out-of-band restrictions on these ARNS systems
  - ADS-B OUT, ADS-B IN, and TCAS application protection have far more demand on spectrum protection then Aireon's surveillance safety service
- Aireon Supports Global Flight surveillance and Tracking Services

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