Space-Based ADS-B

Details and Uses

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McLean, Virginia, USA

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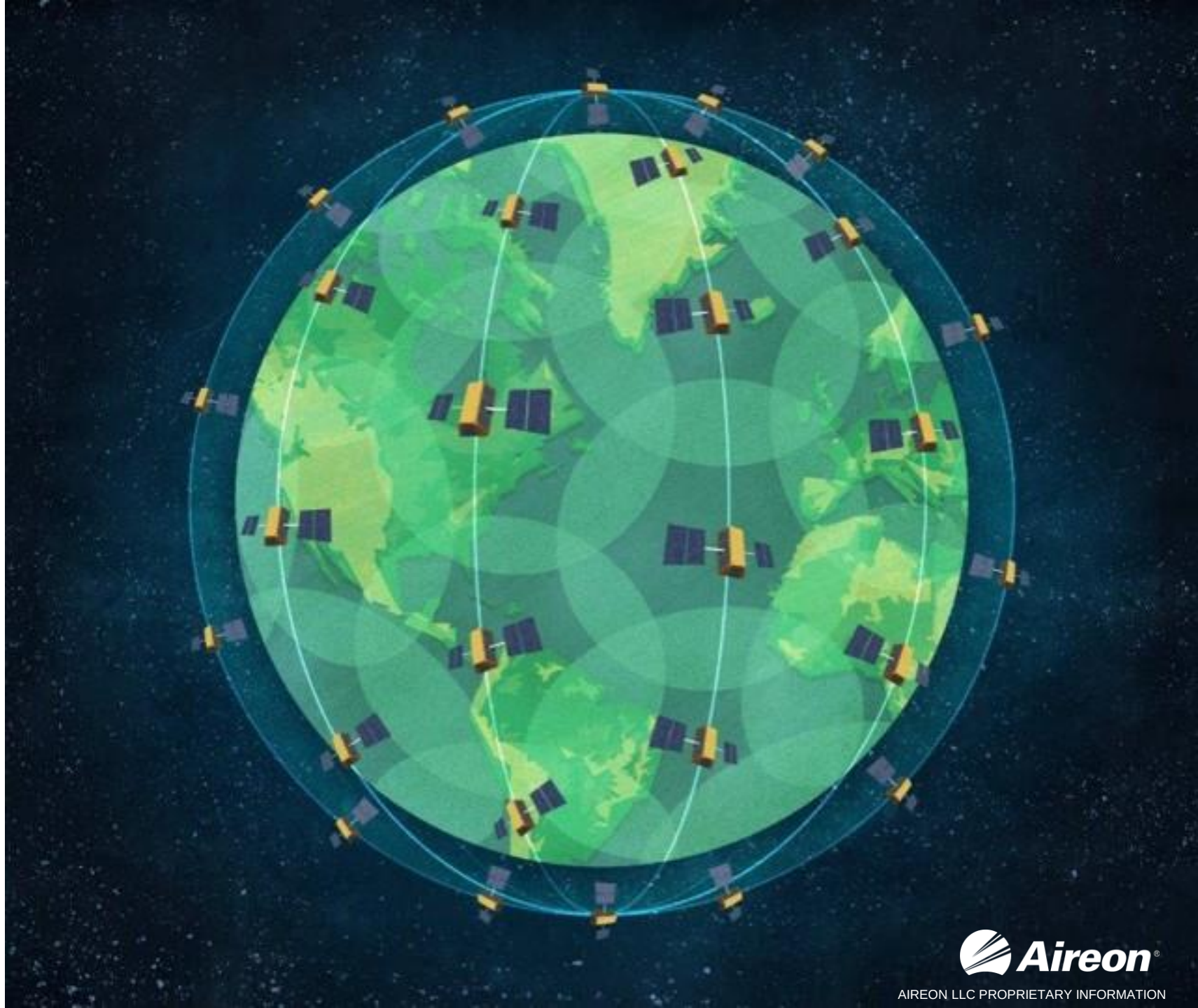
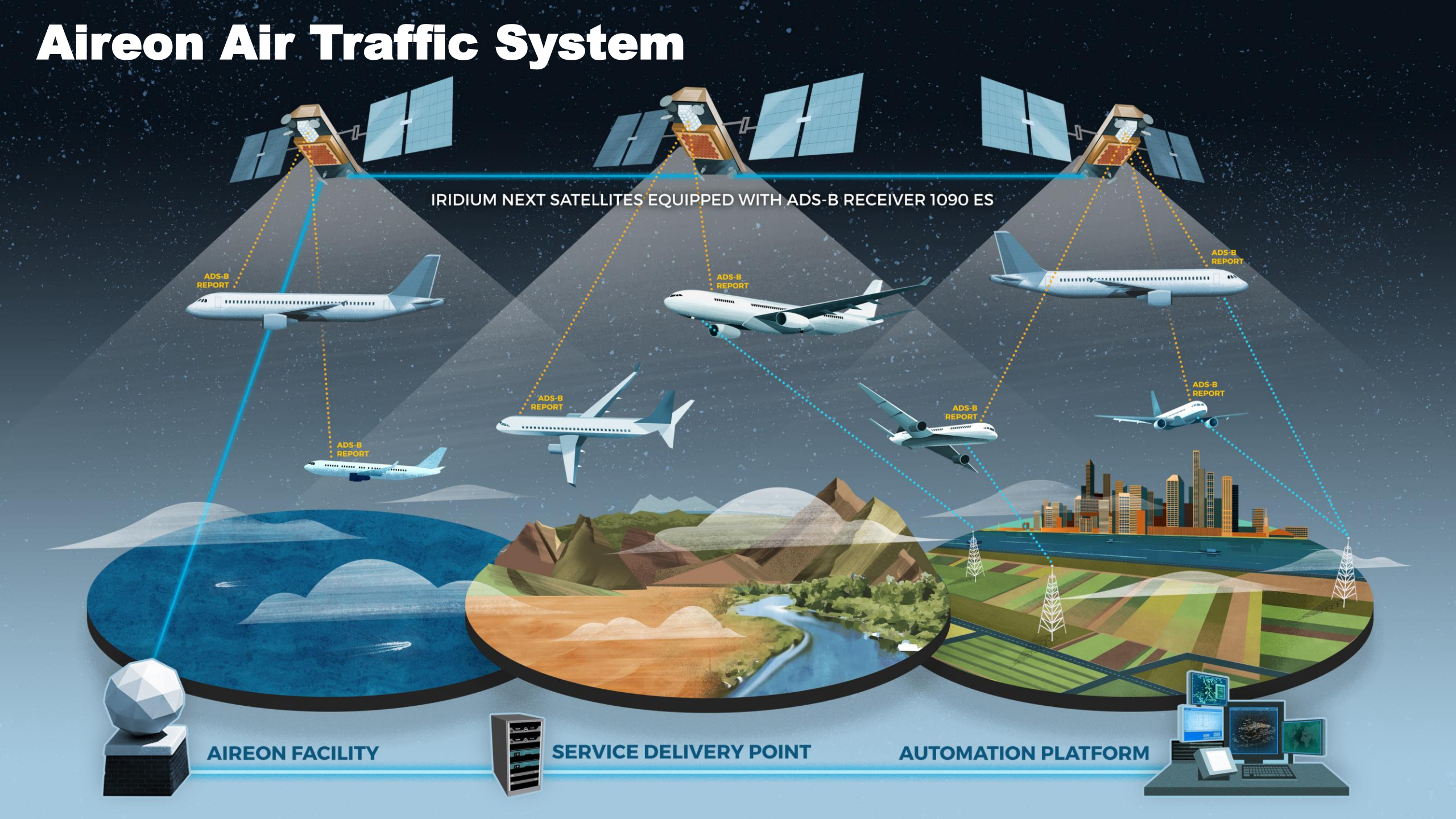
Topics

- Aireon System Overview
- Aireon Customers and Integration
- Aireon Performance in Latin America
- Independent Position Validation

Aireon System Overview



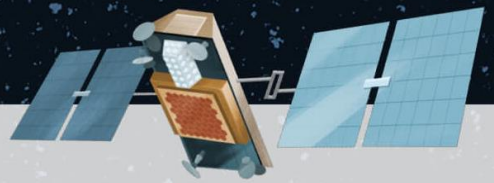
Aireon Air Traffic System



Aireon System Functional Description

- **The space segment** utilizes Iridium's constellation of 66 satellites distributed in six polar orbital planes.
  - Each satellite contains the Aireon Hosted Payload (HPL) that receives, demodulates and transfers ADS-B messages from equipped aircraft.
  - Data is then routed over crosslinks between Iridium satellites and downlinked to an Iridium teleport. On reaching a teleport, downlink data is routed via a terrestrial network to the ground segment.
- **The ground segment** is comprised of the Hosted Payload Operations Center (HPOC), the Aireon Processing and Distribution (APD) center and the Service Delivery Point (SDP).
  - The HPOC provides all the functions required to monitor and control the Aireon HPL, including telemetry monitoring, failure recovery and remote configuration.
  - The APD provides all processing of ADS-B data, mission planning, payload tasking functions and delivery of data to the ANSP SDP.

Aireon Subsystems



Iridium Satellite

Aireon Hosted Payload (AHP)

1090ES ADS-B Transmission

Satellite Crosslink (as needed)

Aircraft

Iridium Satellite

Aireon Hosted Payload (AHP)

ANSP Service Delivery Point (SDP)

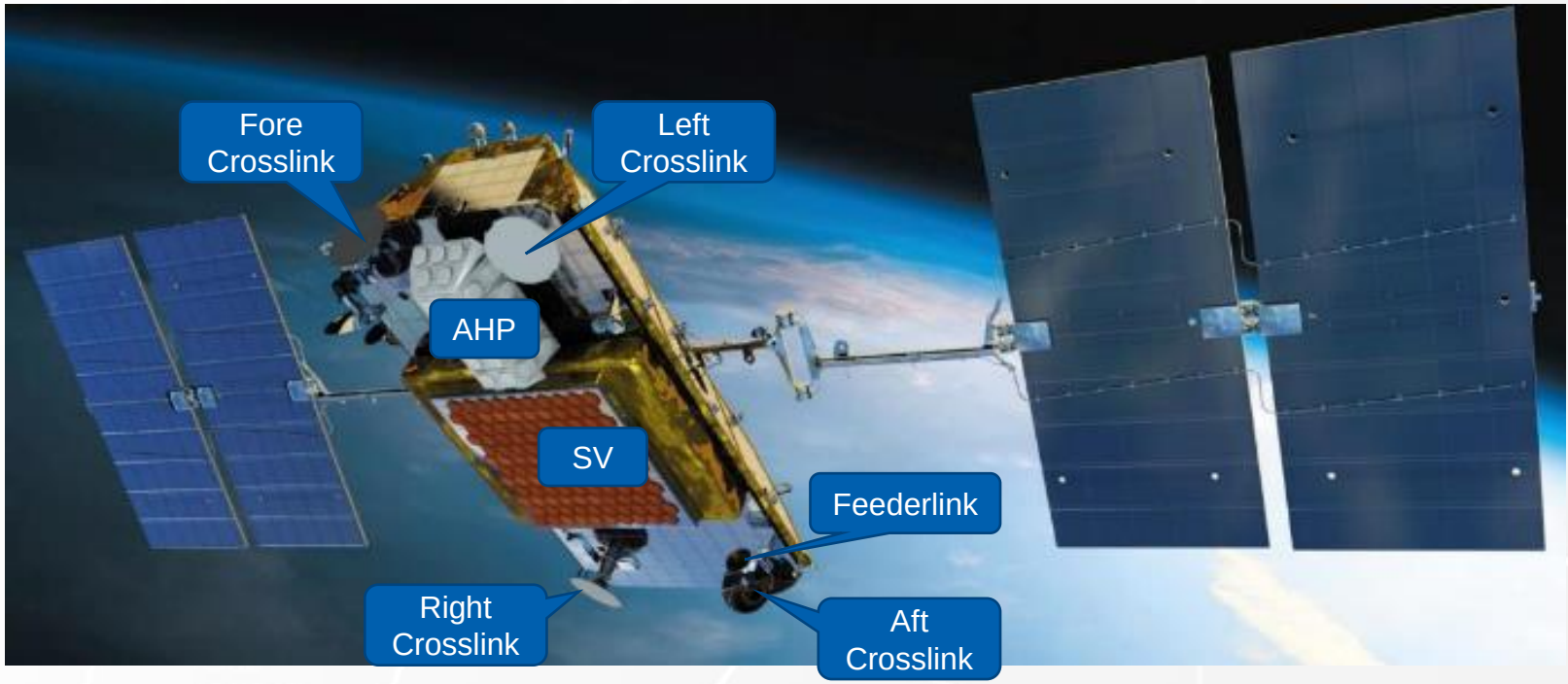
Aireon Hosted Payload Operations Center (HPOC)

Aireon Processing and Distribution (APD)

Teleport Network (TPN)

Space Segment

1. The Aireon Hosted Payload (AHP) receives and decodes ADS-B messages
2. The Iridium Satellite Vehicles (SV) communicate with one another via the Crosslinks
3. The SV communicates with the TPN via the Feederlink



Teleport Network (TPN) Site

Aireon Uses 3 TPN Sites

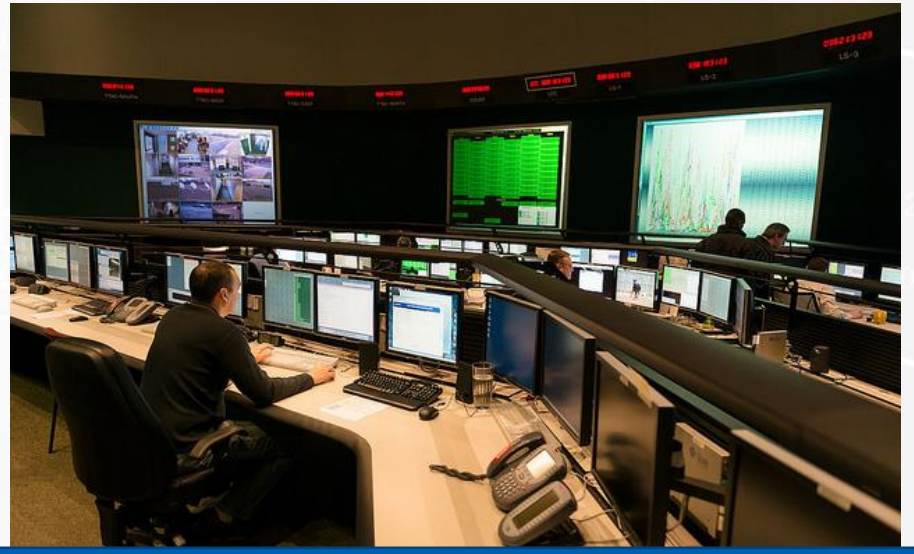
1. Svalbard, Norway
2. Fairbanks, Alaska
3. Punta Arenas, Chile

Ground Segment

Primary Functions of the HPOC:

1. Monitor Status of Hosted Payload
2. Manage Command/Control/Status information between HPL and APD
3. Deliver Mission Data to APD

Primary HPOC

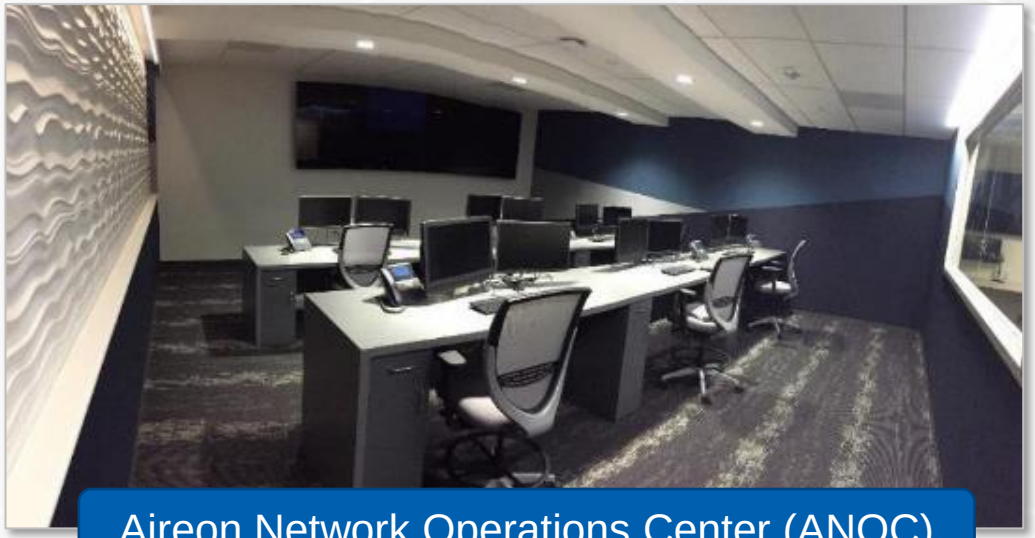


Hosted Payload Operations Center (HPOC)

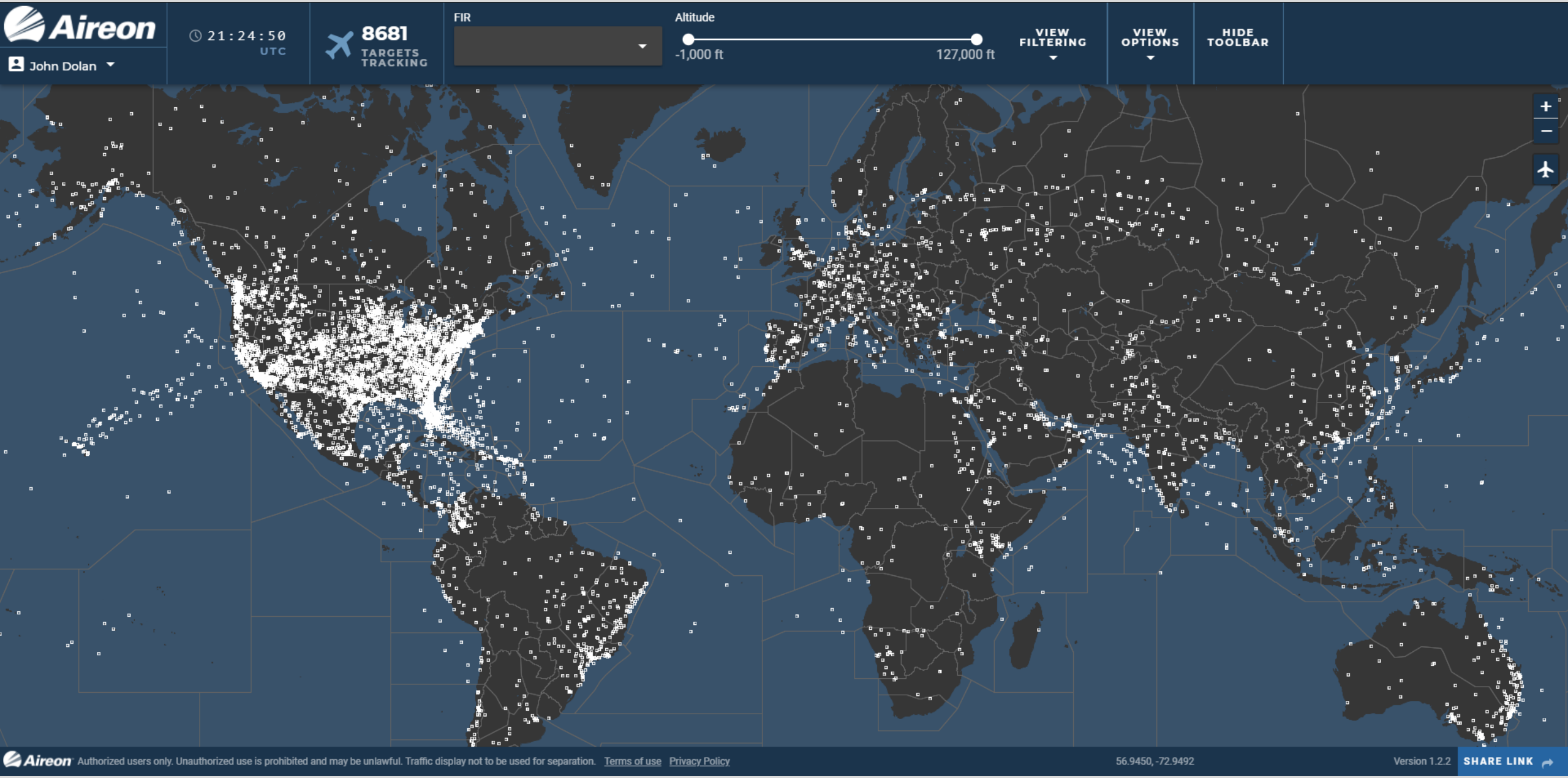
Primary Functions of APD:

1. Deliver ADS-B Reports to ANSPs
2. Monitor system applications and assets
3. Command and Control AHP
4. Report status of systems, service volumes, and coverage to ANSPs

APD Primary Control Station



Aireon Network Operations Center (ANOC)



Space-Based ADS-B Differentiators

- How is space-based ADS-B (SBA) different from a terrestrial system:
  - Global coverage: Aireon's HPLs on the Iridium satellites provide full, overlapping coverage of the entire globe.
  - No line-of-sight obstructions: Unlike ground stations there are no terrain impacts to SBA; it can see to the ground at any location.
  - Surveillance-as-a-service: Aireon provides data to customers and handles the maintenance and updates to the system with customer support governed by a Service Level Agreement (SLA).
  - Top antenna required: Because the receivers are high in orbit, SBA performance is best when the aircraft has a top mounted antenna.

Service Level Agreement

Metric Title	Metric Value
Service Volume Availability	≥ 99.9%
Service Volume Continuity	≥ 9,871 hours Mean Time Between Unexpected Critical Failures
Service Software Assurance Level	The following software assurance level has been allocated to all Aireon System Software Configuration Items where a failure mode may impact the safe provision of Aireon Surveillance services. • ED-109A/DO-278A AL4 • ED-153 SWAL3
ADS-B Target Report Latency	≤ 1.5s (99th percentile)
Probability of Update	≥ 96% for an Update Interval of 8 seconds
Technical Support Response Time	No greater than 2 Hours
Problem/Trouble Report Response Times	Category 1 – Critical: maximum of 24 hours Category 2 – Major: maximum of 7 days Category 3 – Minor: coordinated with the ATSP scheduled Service updates

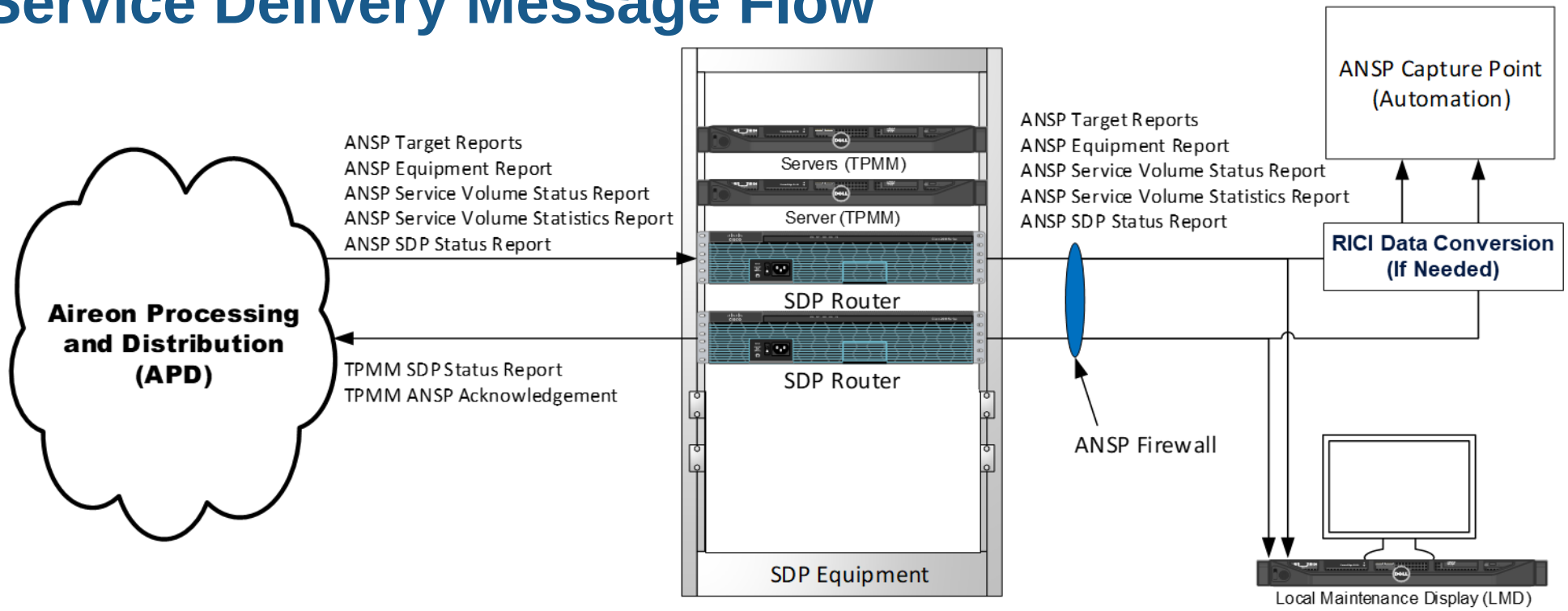
Indicates a Technical Performance Metric

Aireon Customers and Integration

How Aireon Delivers Data

- Once the ADS-B messages have made their way to the ground and been processed by the APD they are sent to customers.
- The Aireon data is formatted and sent in the EUROCONTROL ASTERIX formats:
  - ADS-B data is formatted into CAT021 or CAT033 (FAA) messages.
  - Other ASTERIX formats are used for status information.
- This data is sent to our SDP which then connects to the customers automation platform:
  - If the platform can natively use ASTERIX formats no modification should be necessary.
  - If the platform requires a different version of message Aireon utilizes a conversion product to reformat the data (RICI).

Service Delivery Message Flow

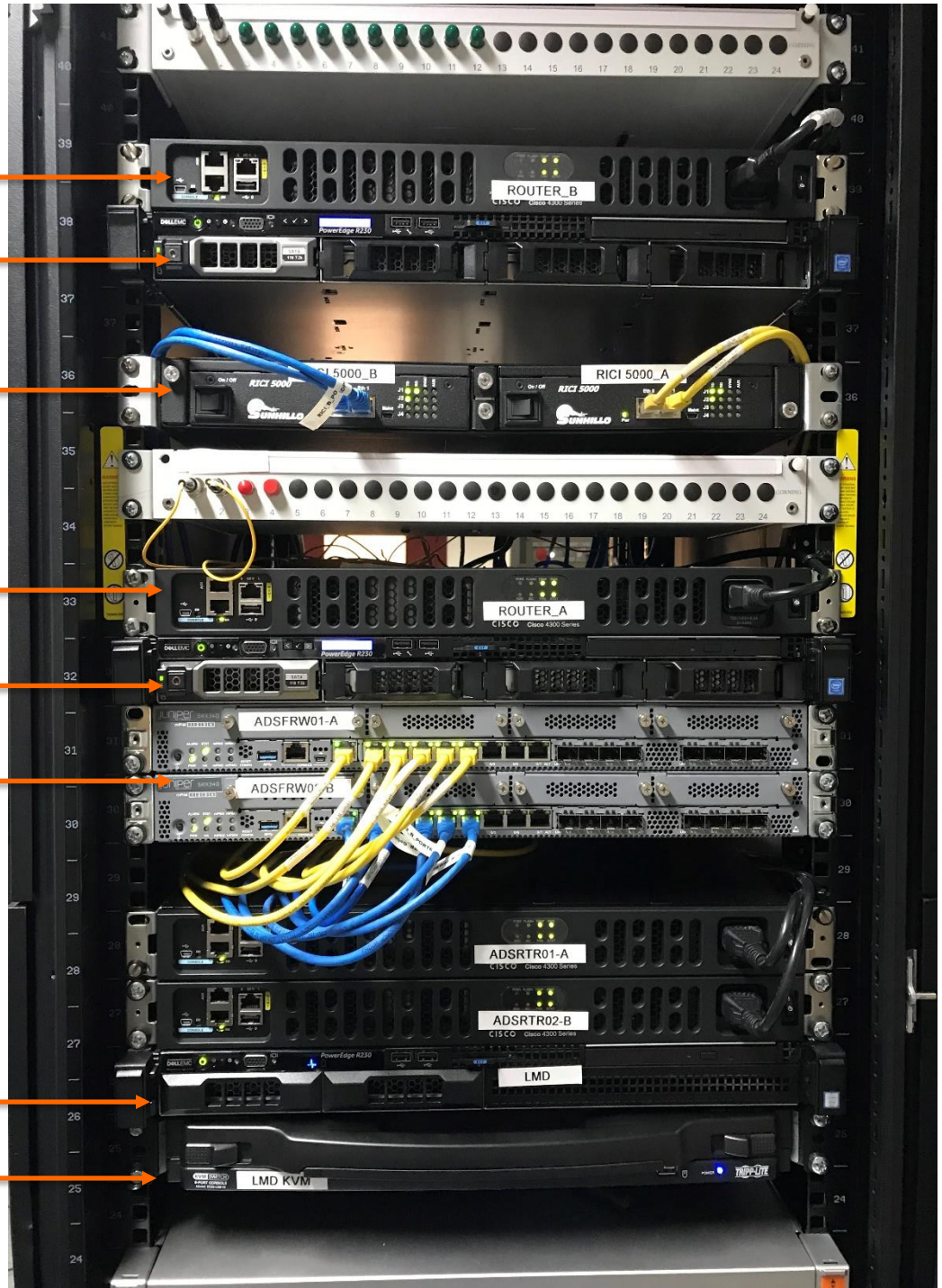


- **Aireon Service Delivery Point (SDP)**
  - Demarcation between the Aireon system and the ANSP system(s).
  - The SDP tallies the number of messages received at the ANSP for reporting. This feedback loop allows Aireon to monitor SLA performance.
  - SDP consists of COTS redundant monitoring servers and routers.
  - Enables connection of ASTERIX data stream to the ANSP automation system and tracker.

SDP Equipment Overview

- 8U total Rack Space
  - Two Cisco 4331 (Router)
  - Two Dell PowerEdge R340 (TPMM)
  - One Dell PowerEdge R340
    - (Local Maintenance Display)

- Additional equipment may include:
  - RICI
  - Firewall / Switch
  - KVM



Local Maintenance Display (LMD) Overview

- Used to show key status for ANSP service volumes per ED-129B requirements:
  - Service volume mode – operational, standby or Maintenance
  - Service Volume State – Running, Degraded or Failed
  - Service volume noGo flag – True or false
  - Message ID – Unique identifier of the status message
- Used to show faults and errors:
  - Target overload
  - Communications overload
  - Time source invalid or coasting
- Air Situation Display (ASD) used to display aircraft targets within the ANSPs service volume(s):
  - Ensures CAT021 messages are being properly received

Real-Time Interface and Conversion Item (RICI)

- Sunhillo Real Time interface and Conversion Item (RICI) 5000:
  - Modular platform designed for surveillance sensor data formatting, filtering, and protocol conversions
  - ADS_B Message conversion from CAT021 v2.4 to CAT021 v0.26 or 0.23
  - Power usage:100-240 VAC, 2.0A Max, 50-60Hz
  - IEC connectors for international compatibility

Project Approach to Deployment and Operations

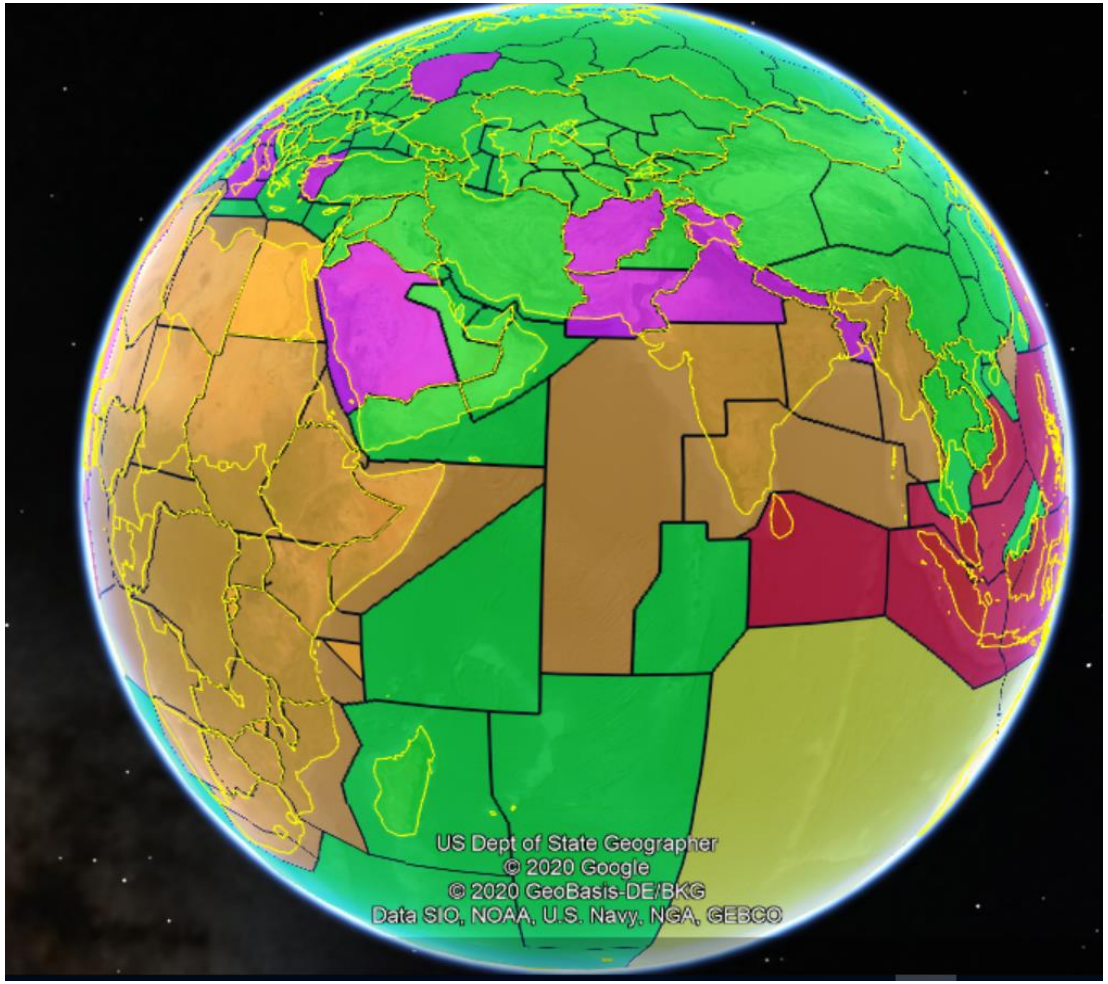
- Objective: Establish ATC-grade surveillance-as-a-service:
  - Implement three-phase process per the statement of work:
    - Phase 1: Initial planning and project definition
    - Phase 2: Establish SDP
    - Phase 3: Service acceptance

Phase 1: Initial Planning and Project Definition Milestones

- **Established technical requirements and project-level resources for each phase of the project:**
  - Travel to ANSP facility for site survey to gather information for site preparation and installation activities.
  - Where will the SDP will be located?
    - Equipment room?
    - Rack location?
    - SDP co-location
    - LMD location
    - Proximity to telco demarc
    - Power outlet type
  - Facility and equipment critical power?
  - Telecommunications demarc location?
  - Automation system and version
  - ASTERIX version
  - Establish integrated master schedule

Phase 2: Establish Service Delivery Point

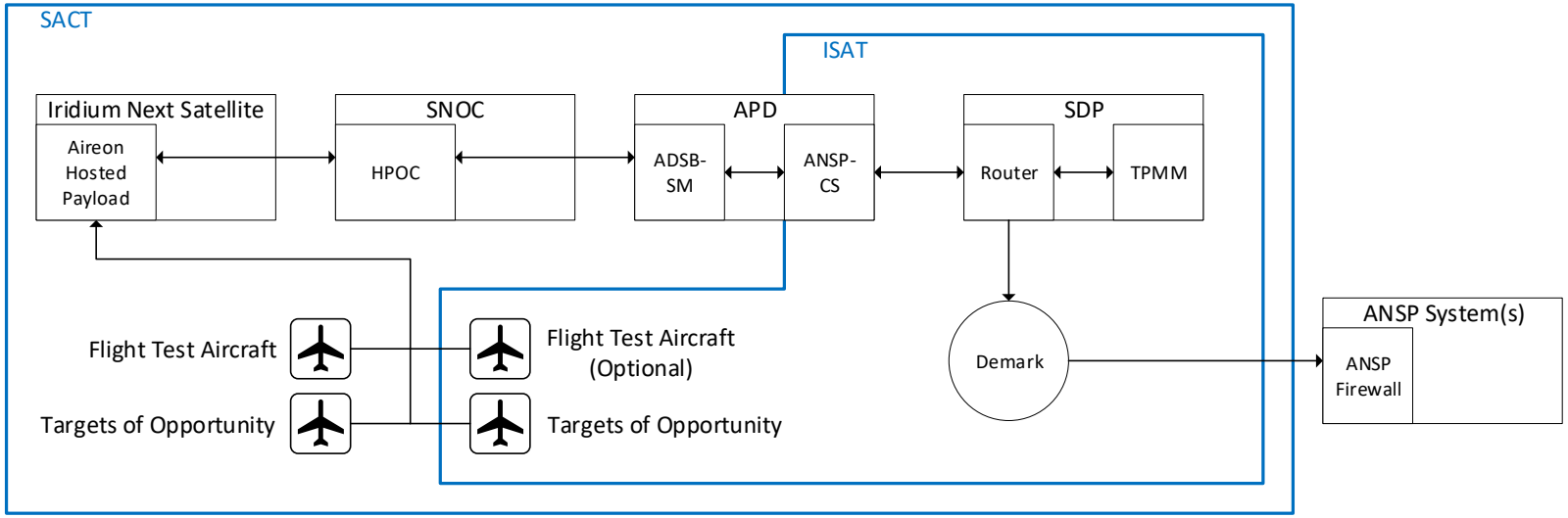
- Procure and ship SDP and coordinate with ANSP to install the equipment once arrived
  - TPMMs, Routers, Router Components, Cables and LMD.
- Service Volume Description Document (SVDD):
  - Captured parameters necessary for various Aireon subsystems including ANSP service configuration, service volume definition, geometry, target reporting an SDP configuration.
- Order redundant MPLS lines for ANSP facility and conduct MPLS checkout to ensure APD to telco circuit connectivity.
- Perform SDP checkout:
  - Assess the SDP baseline service delivery and system performance.
  - Checkout is in preparation for the formal test event (i.e. ISAT).



Phases 3 – Implementation Service Acceptance Testing (ISAT)

- **Phase 3: Service acceptance testing**
  - ISAT to verify that data services are completely installed, optimized and ready to transition to ANSP air traffic operations:
    - Procedures developed by Aireon and reviewed by the customer.
    - Test conduct and execution witnessed by customer.
    - Aireon deliver test report at the conclusion of the ISAT including:
      - Aireon / ANSP satisfy exit criteria for Phase 3 ISAT
- **Operational data service**
  - Aireon delivers operational data service to the SDP – Go Live!
- **ISAT entry criteria**
  - Equipment installed and checkout completed.
  - Test tools qualified to DO-330 / ED-215.
  - SVDD configurations defined, baselined and deployed.
  - Test artifacts developed and delivered.

Generic ISAT – Overview



- Telco and installation test cases
- Security test cases
- System configuration test cases
- Data collection
- Performance test tases
- Redundancy test cases
- Operations test cases
- Billing test cases
- Customer-specific test cases

ISAT Exit Criteria

- Aireon / ANSP execute all test procedures and agree on pass / fail / defer status for each test case.
- Aireon document test results in accordance with executed results.
- Aireon ISAT deliverables reviewed and accepted by ANSP as set forth in the Document acceptance process in the SOW:
  - ISAT test plan
  - ISAT test procedures
  - ISAT test report
- Close out open action items with the customer.

Aireon's Users

- Aireon currently provides SBA data to users around the world including
  - FAA
  - NAV CANADA
  - COCESNA (Central America)
  - NATS (UK)
  - AAI (India)
  - CAAS (Singapore)
  - NAV Portugal
  - ASECNA (Western Africa)
  - DC-ANSP (Curacao)
  - And many others…

Space-Based ADS-B Benefits

- Increase in flights being granted requested flight level, speed and point of entry into airspace.
- Reduction in crew and controller workload by reducing the reliance on ad-hoc position reporting.
- Early warnings when aircraft deviations take place or are about to take place.
- Improved accuracy of position data during events.
- Gathering information on flights outside of their current surveillance capabilities.
- Improved airspace capacity and reduction of unnecessary delays.

Performance in Latin America

Performance

- Aireon primarily measures performance based on three key Technical Performance Metrics (TPM):
  - Availability: System uptime compared to the sample duration.
  - Latency: Time between message reception at the AHP and delivery to the customer.
  - Probability of update and update interval: Measurement of the rate that messages are delivered to the customer for aircraft.
- These metrics are measured per customer service volume or FIR and depend on the location, traffic composition and environment.

Availability

The Aireon System shall provide end-to-end service availability >/= 0.999.
Note: This availability is typically calculated for each customer service volume on a monthly basis.

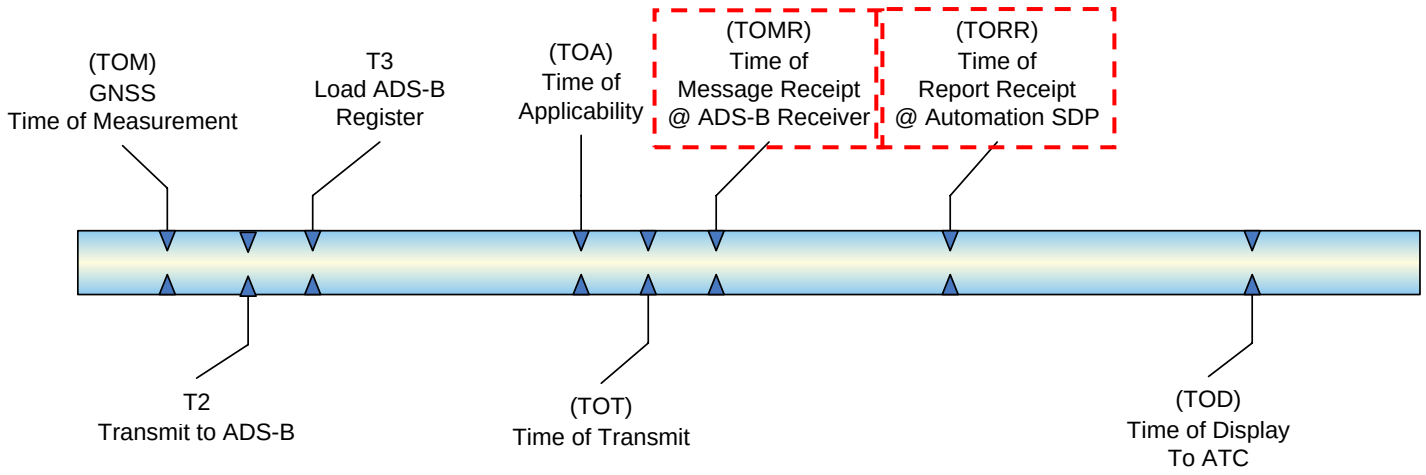
- Aireon service availability:

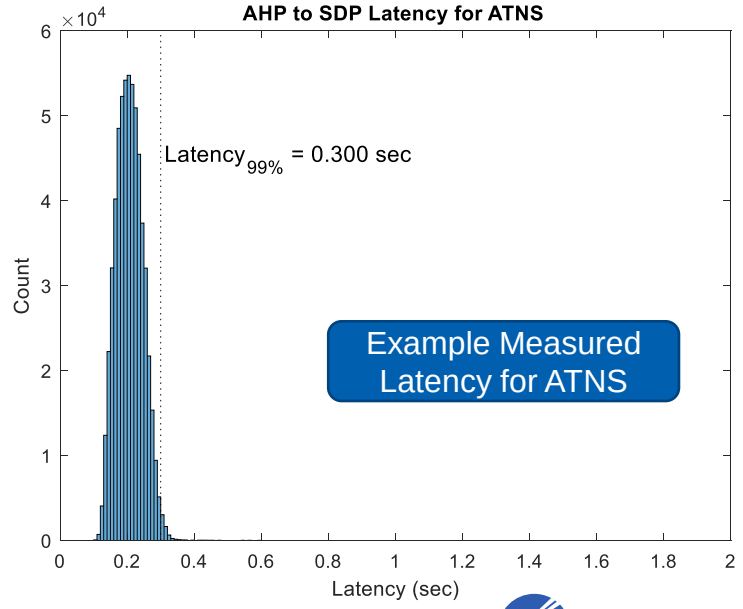
$$A_{SV} = \frac{\beta}{N} = \frac{Uptime}{Uptime+Downtime}$$

- β = Actual daily system operational uptime derived from status report counts at the SDP.
  - Service volume availability includes outages for both planned activities, like maintenance and, unplanned activates like component failure.
- N = Expected operational system time which is a constant daily value.

Latency

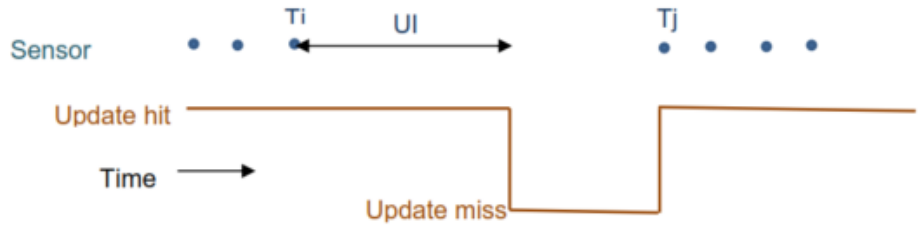
- Total latency: The end-to-end time starting from the Time of Applicability (TOA) of the position until the target is displayed at the controllers position (TOD).
- Aireon service latency (TOMR to TORR): Must be below 1.5s (99th percentile)





Probability of Update

- For each aircraft, the UI metric is based on the following series of equations (extracted from ED-129B, Appendix C)



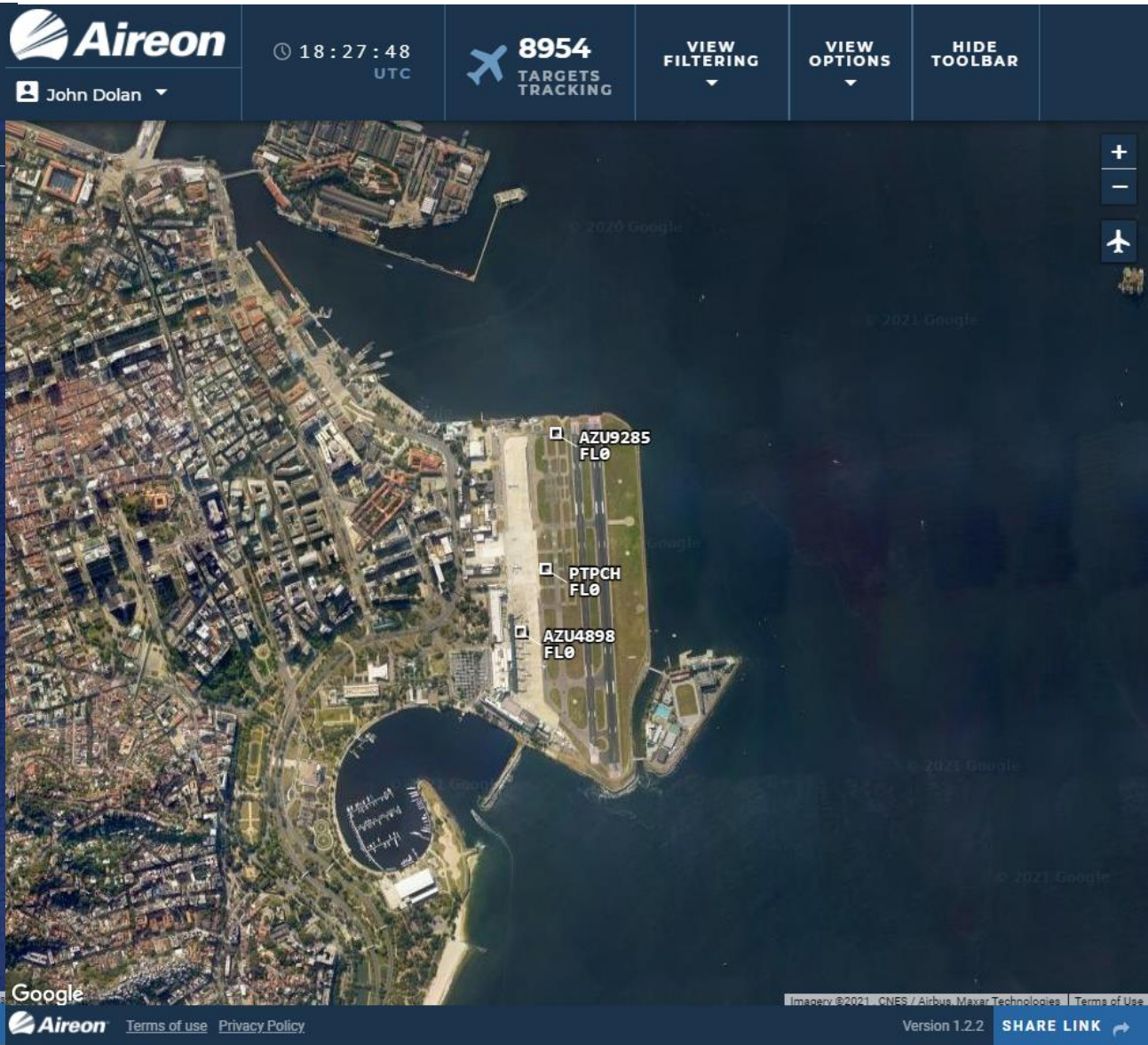
- Equation 1:
  - *Miss period i=If G>UI then G-UI, else 0* {for reports (i) in each trajectory}
  - *Where G=the measured gap miss time Time (s) and UI=the required Update Interval (e.g. 8s)*
- Equation 2 (UI exceedance time):
  - *Total miss period=*$\sum_{i=1}^{N}$ *Miss period (i)* {from trajectories within the applicable volume}
- Equation 3:
  - *Total flight duration= total duration of trajectories* {within the applicable volume}
- Equation 4:
  - *PU=1-(Total miss period ÷ Total flight duration)*
  - *PLG = Total miss period (with UI=3*UI)÷ total flight duration*

Design considerations for PUI
- RF interference environment
- Overlapping satellites (changes by latitude)
- Aircraft Tx power, antenna gain pattern and antenna diversity
- Rules of Compact Position Report (CPR) processing

Performance in Latin America

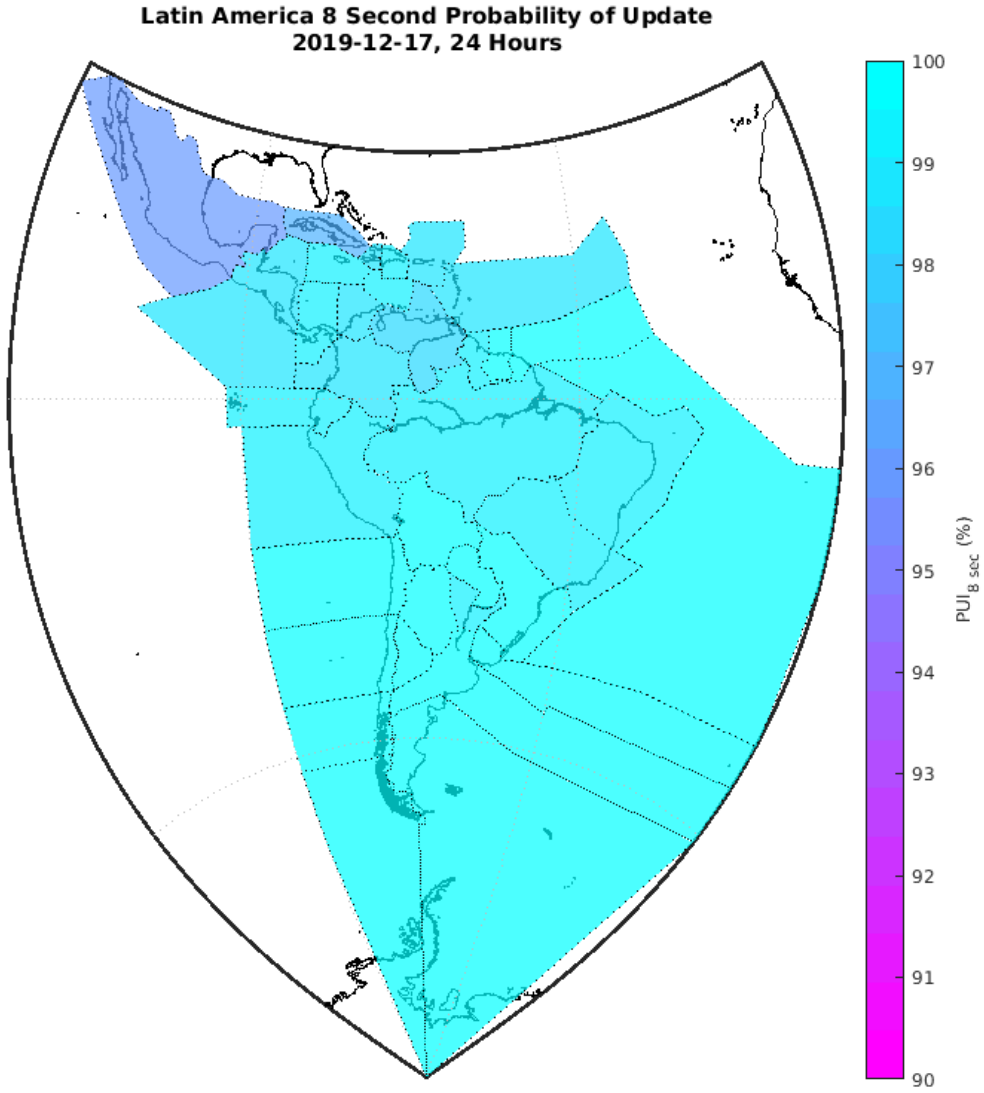
- Analysis done on SBA performance in Latin America has shown excellent values in all three TPMs:
  - Availability: Usually constant across all customers and based on system outages.
  - Latency: Again, constant for most customers with slight variations on the order of a few hundred milliseconds.
  - Update Interval: The most variable TPM across customers. All Latin America FIRs perform very well.
    - Aireon's goal metric is an 8s Probability of Update (PUI) of 96%.
- An evaluation done in December 2019 (pre-COVID-19) found that nearly all of Latin America was able to maintain an eight second PUI in excess of 98%.

Display of Traffic

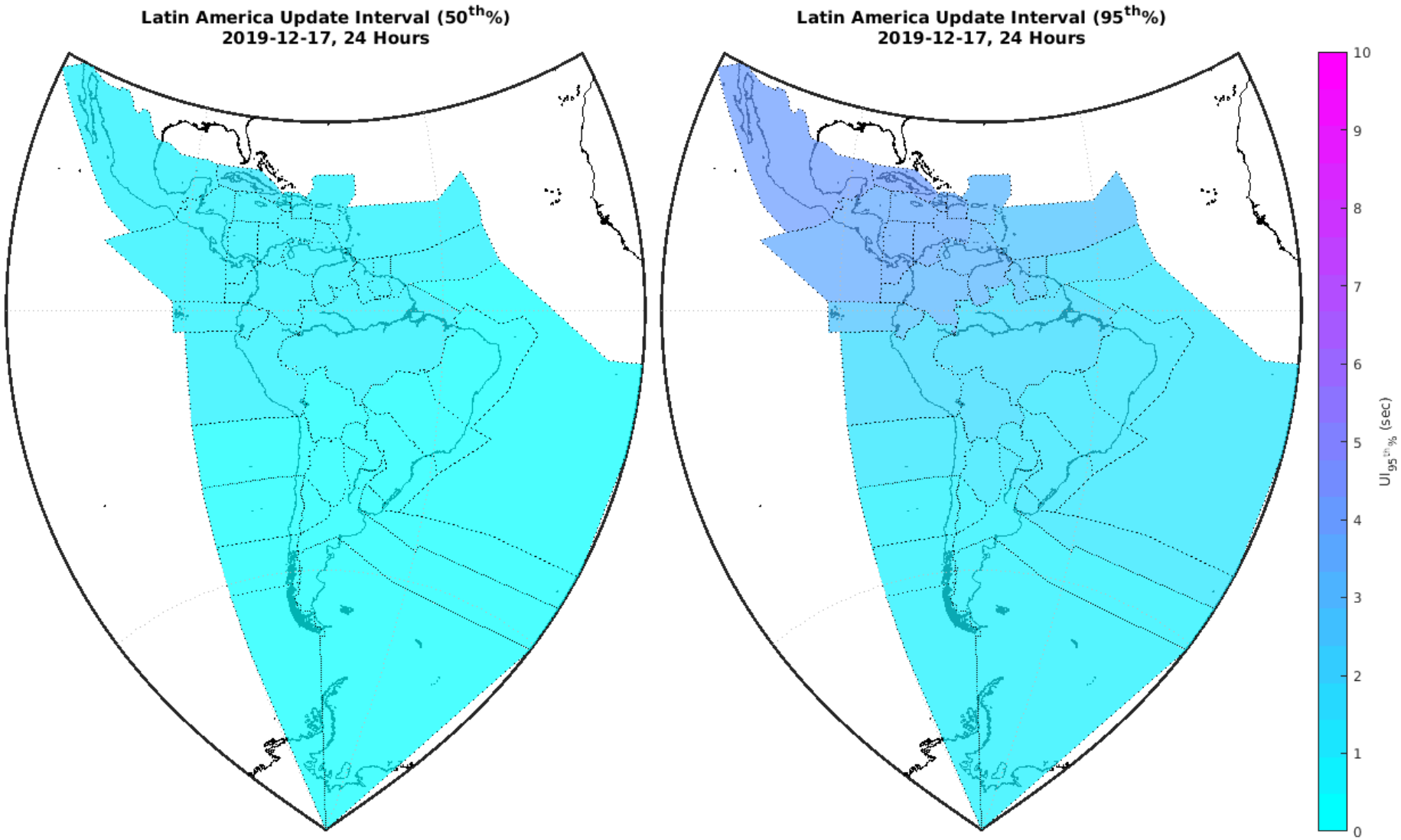


Eight Second PUI

- Map of the 8s PUI over a 24-hour period for all Latin America.
- Only two regions had slightly lessor performance: Mexico and Cuba
  - Aireon has made multiple improvements to system configuration to improve probability of detection for all customers around the world.
  - Measurements are difficult with the current reduced traffic load due to COVID-19.



50th & 95th Percentile UI



- Using a simpler 50th and 95th percentile evaluation across each FIR shows excellent values.
- Average update rate is around two seconds or less.
- 95th percentile is well below eight seconds.

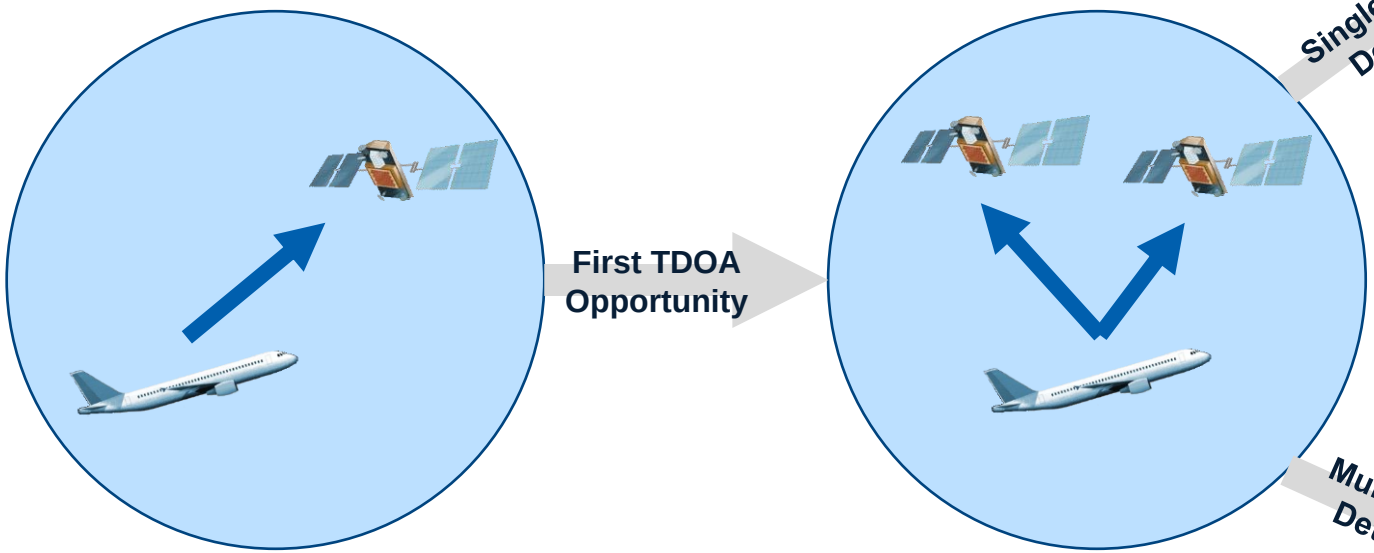
Independent Position Validation

Independent Position Validation

- As an added service Aireon has developed a method to validate ADS-B reported positions using non-position data:
  - This protects against faulty avionics or malicious spoofers
- This algorithm relies on Aireon's overlapping satellite coverage and GPS velocity's independence from GPS position.
- With this functionality Aireon can deliver in each of its reports an indication if the aircraft or report is in question.
- This feature is an optional function that can be enabled for any of Aireon's customers.

Aireon Position Validation

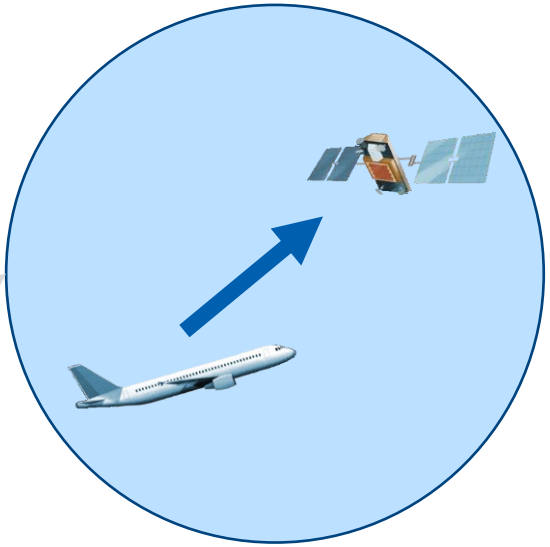
- Validation State is determined with distance between reported position and reference track as well as confidence in reference track
- Continued TDOA observations improve reference track confidence



First TDOA Opportunity

Single Satellite Detections

Multi Satellite Detections



One or more satellites receive a position message

- Initiate reference track with Reported position
- Reference track is **provisional**
- Validation state is **unknown**

Two or more satellites receive any ADS-B message

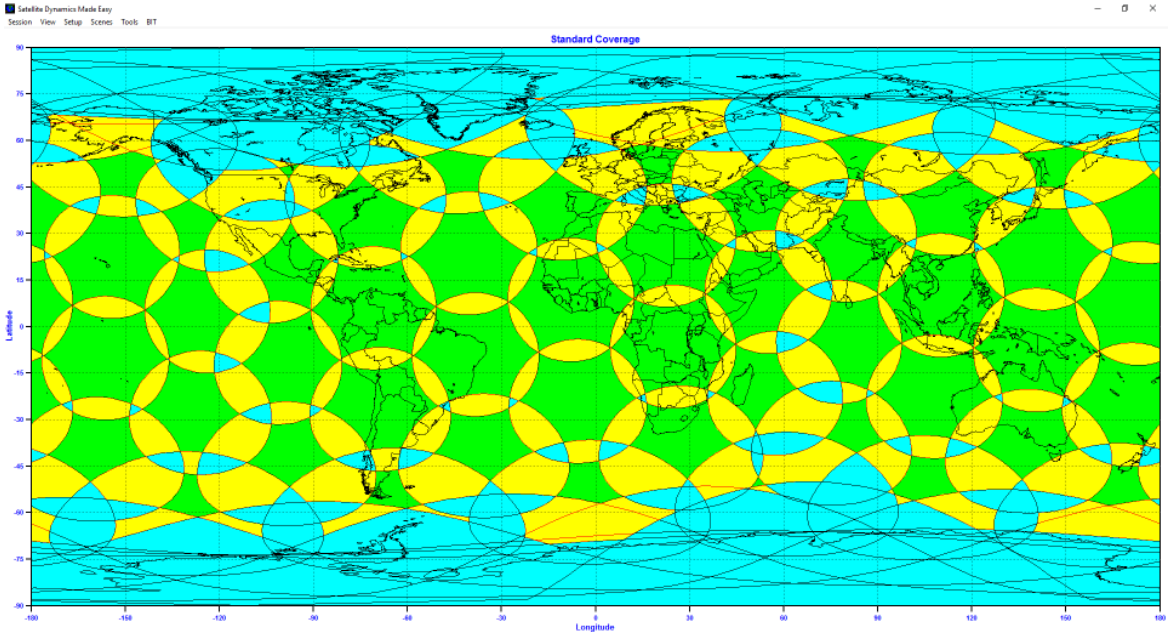
- Update reference track with TDOA observation
- Reference track is now **available**
- Validation state is now **valid** or **invalid**

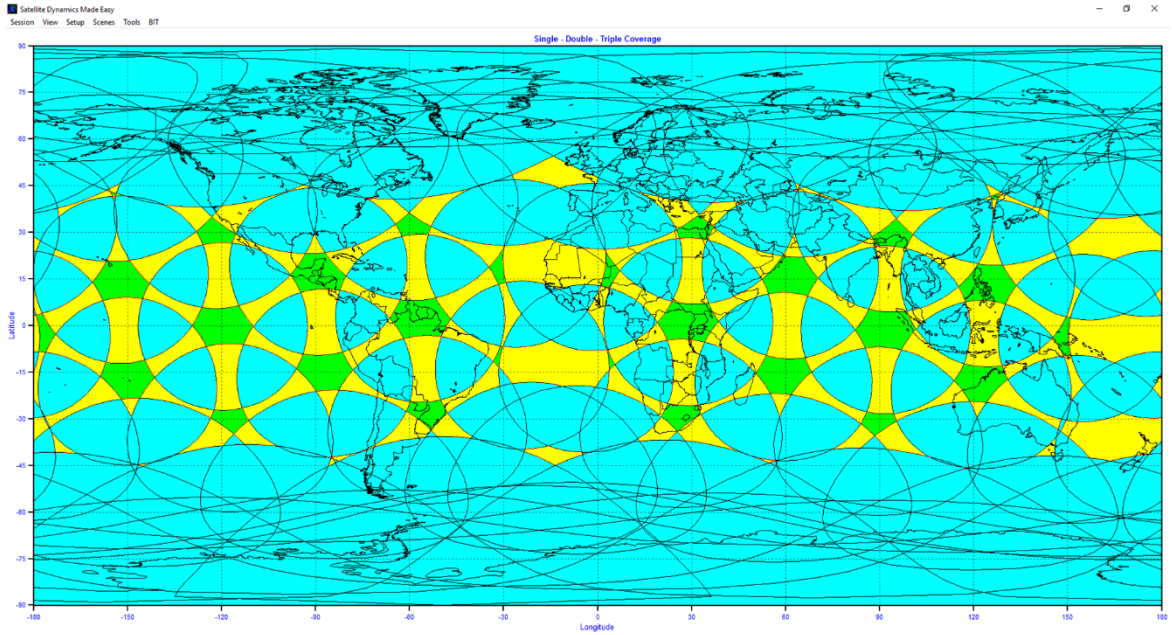
Update the reference track position kinematically with the **reported velocity** and **time elapsed**

Update the reference Track position with **TDOA observation**

Significant Overlap in Footprints

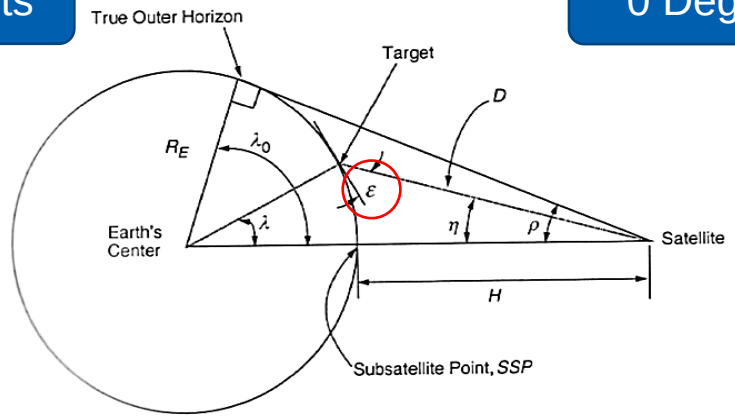
Single Coverage
Double Coverage
Triple Coverage



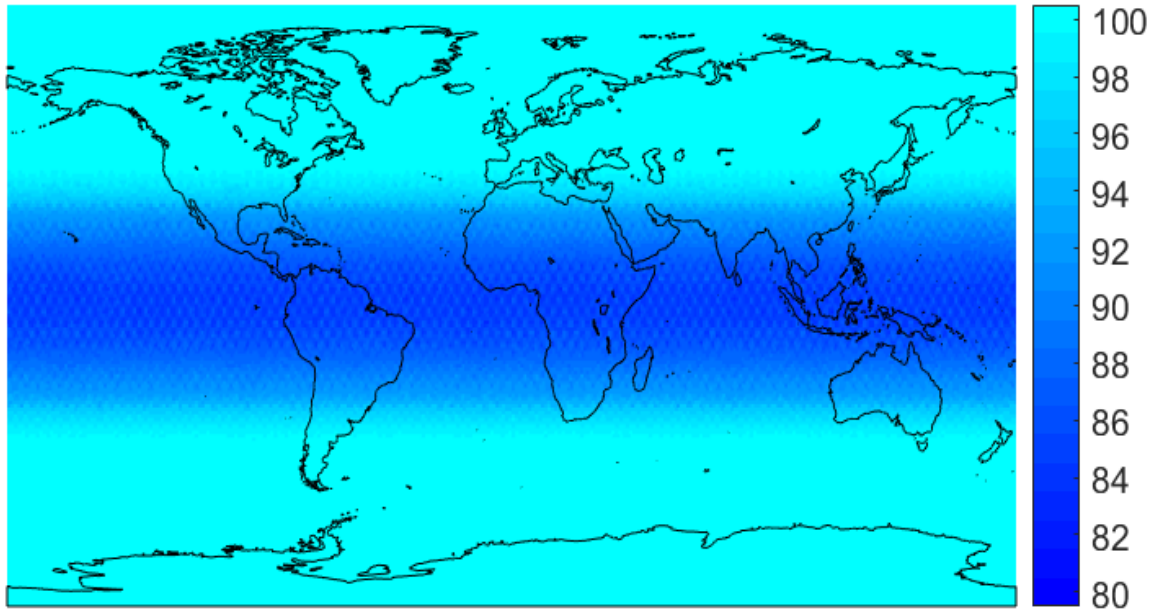


8.2 Degree Elevation Footprints

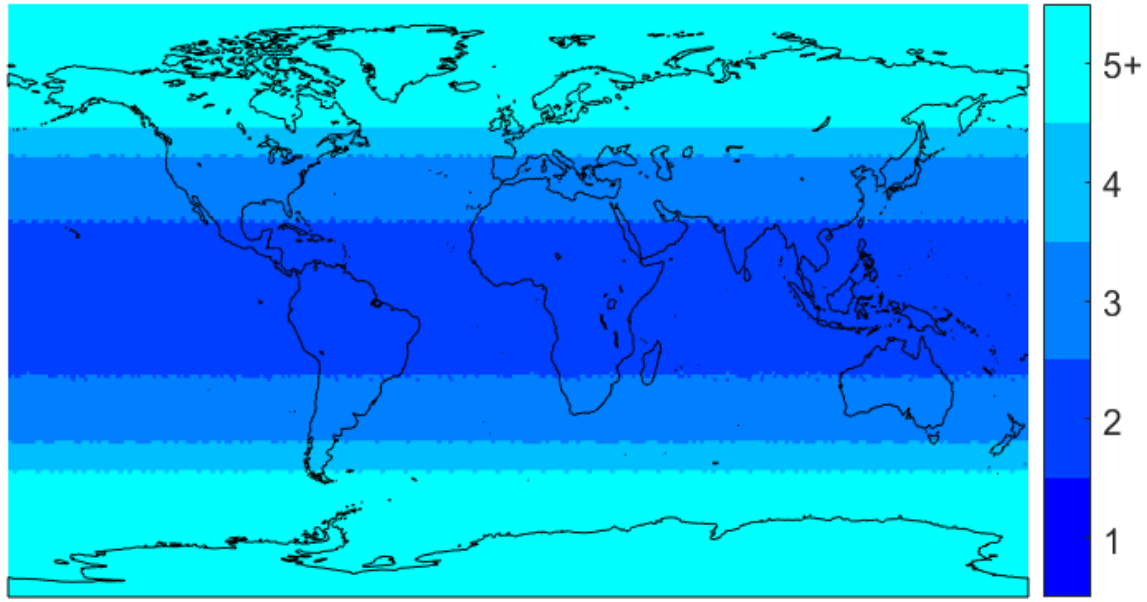
0 Degree Elevation Footprints



TDOA Opportunities



TDOA Probability

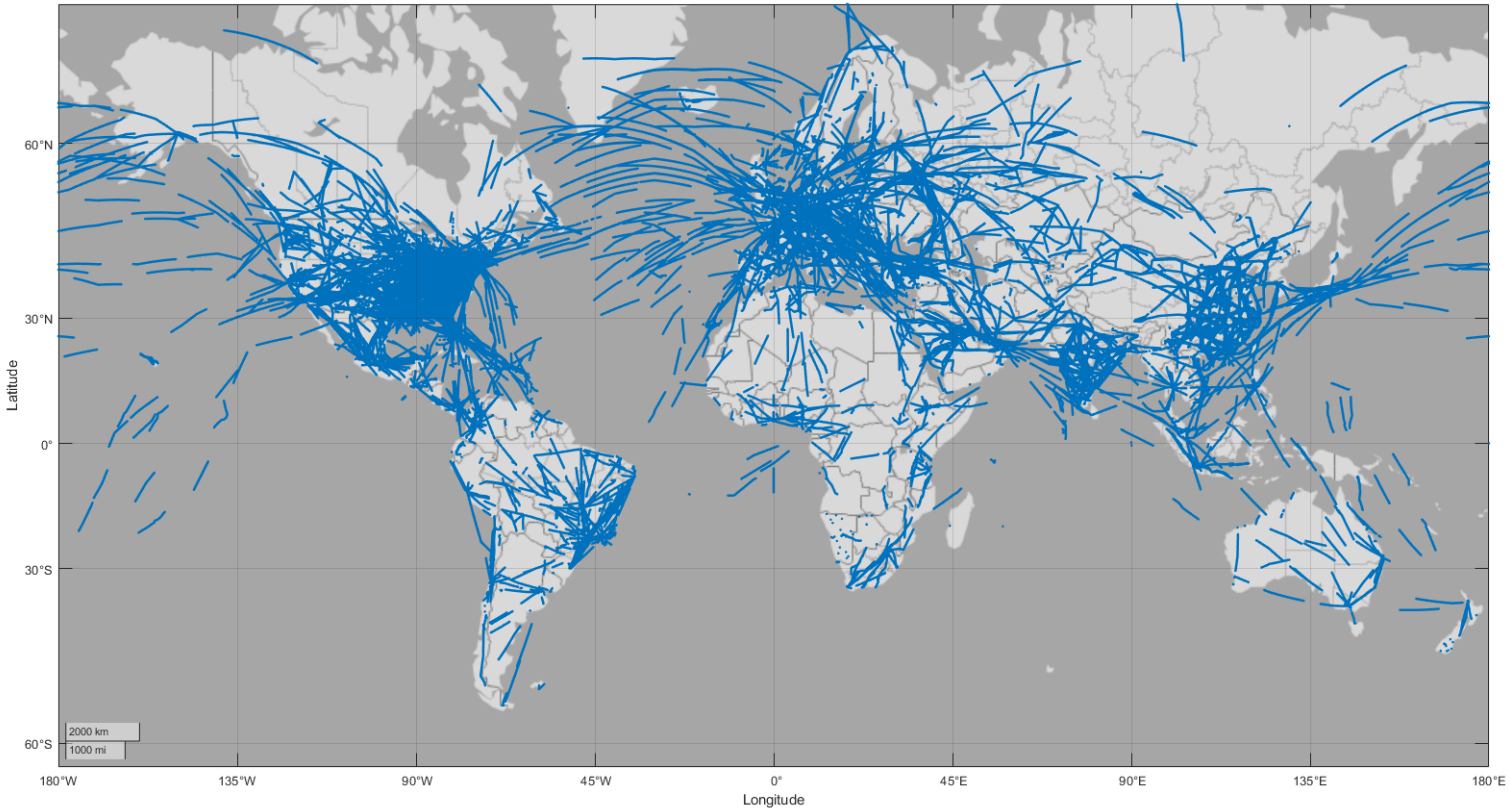


Average Satellite Overlap

- At ±43° latitude an aircraft is always under redundant satellite coverage and will provide ample TDOA opportunities.
- Even at the equator an aircraft will be under redundant satellite coverage 80% of the time.

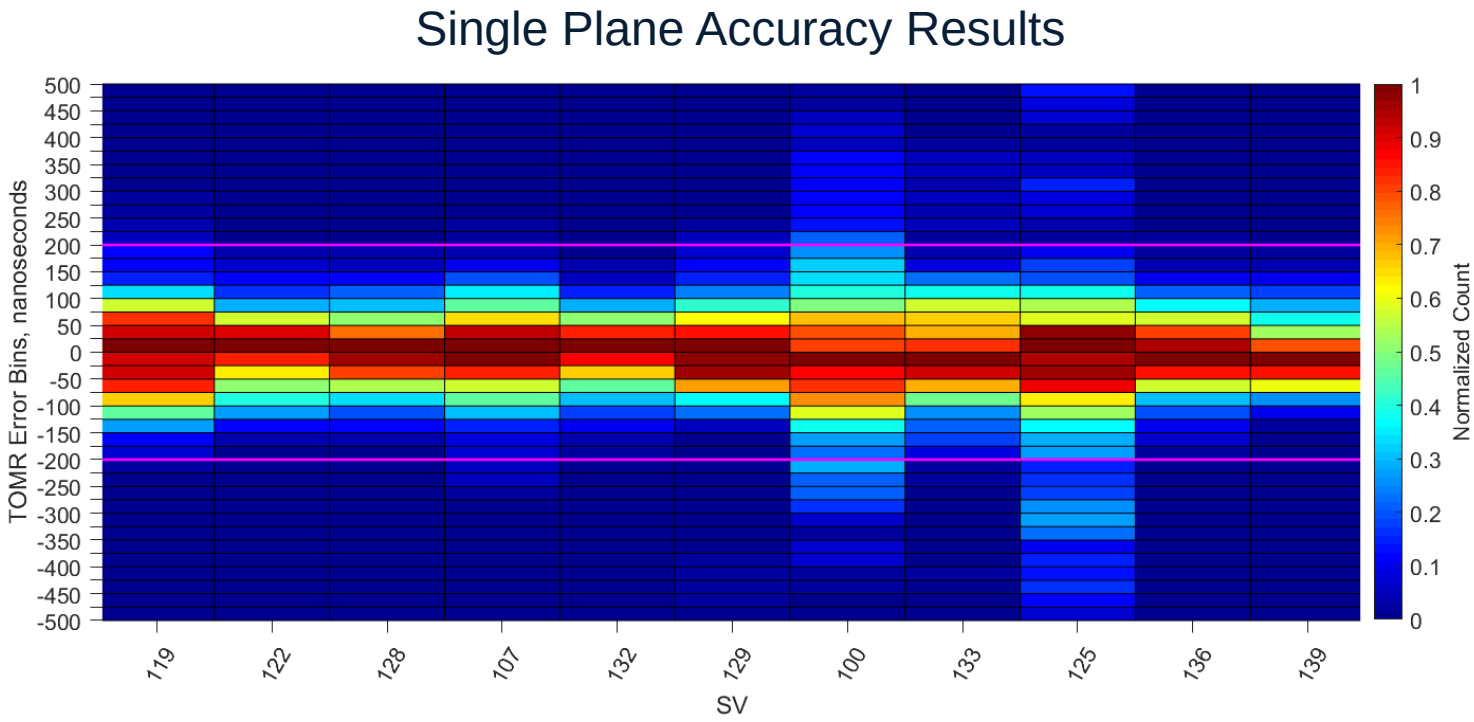
Operational TDOA Opportunities

- Many observations of overlapping coverage in targets of opportunity.
- In a single hour of ~67 million reports ADS-B found ~13 million TDOA opportunities.
- Results found samples all over the globe.



Satellite Position and Timing Accuracy

- The calculations involved rely on accurate satellite position and timing.
- Aireon receives high accuracy information from Iridium that includes satellite positions and time biases.
- With these corrections the overall errors are less than 200 nanoseconds.



Validation Reporting

Structure of I021/040 - Second Extension : Error Conditions

Octet no. 1

8	7	6	5	4	3	2	1
0	LLC	IPC	NOGO	CPR	LDPJ	RCF	FX

Bit-8 : (spare) Spare bit, set to "0"

Bit-7 : (LLC) List Lookup Check
= 0 default
= 1 List Lookup failed (see note)

Bit-6 : (IPC) Independent Position Check
= 0 default (see note)
= 1 Independent Position Check failed

Bit-5 : (NOGO) No-go Bit Status
= 0 NOGO-bit not set
= 1 NOGO-bit set

Bit-4 : (CPR) Compact Position Reporting
= 0 CPR Validation correct
= 1 CPR Validation failed

Bit-3 : (LDPJ) Local Decoding Position Jump
= 0 LDPJ not detected
= 1 LDPJ detected

Bit-2 : (RCF) Range Check
= 0 default
= 1 Range Check failed

Bit-1 (FX) Field Extension
= 0 end of data item
= 1 extension into third extension

NOTES Bit 6, if set to 1, indicates that the position reported by the target was validated by an independent means and a discrepancy was detected. If no independent position check is implemented, the default value "0" is to be used.

IPC Flag in I021/040 of CAT021

Structure (7-octet):

Octet no .1							
56	55	54	53	52	51	50	49
SP Length							

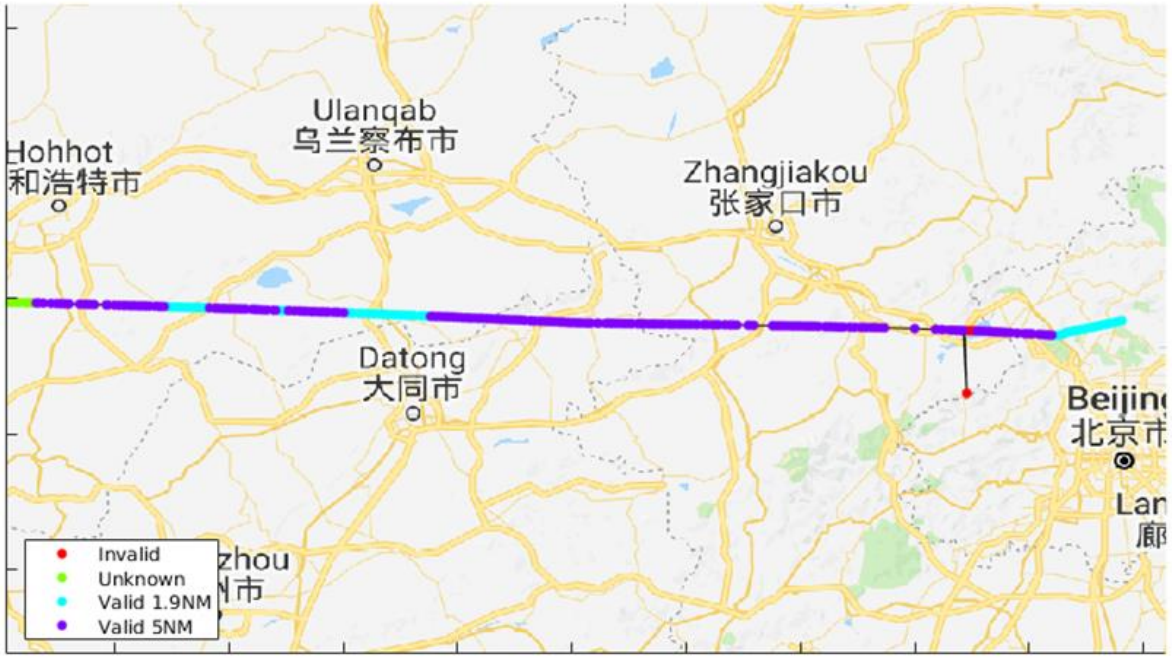
Octet no. 2								Octet no. 3								Octet no. 4							
48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
Message Identifier																							

Octet no. 5								Octet no. 6								Octet no. 7							
24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
SatVID								Validation Distance							Validation State	Validation Radius							

Special Purpose Field of CAT021

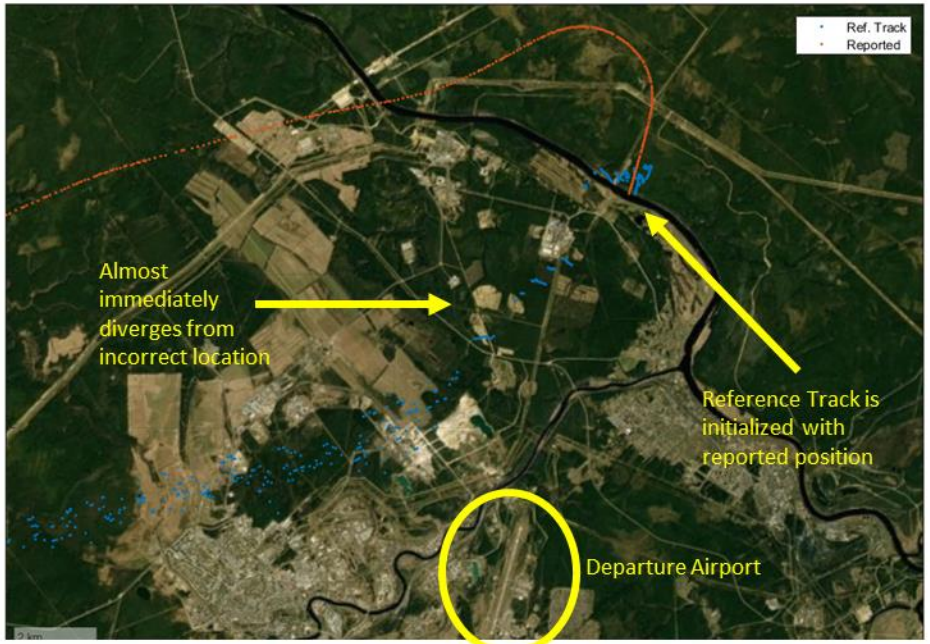
Validation Examples

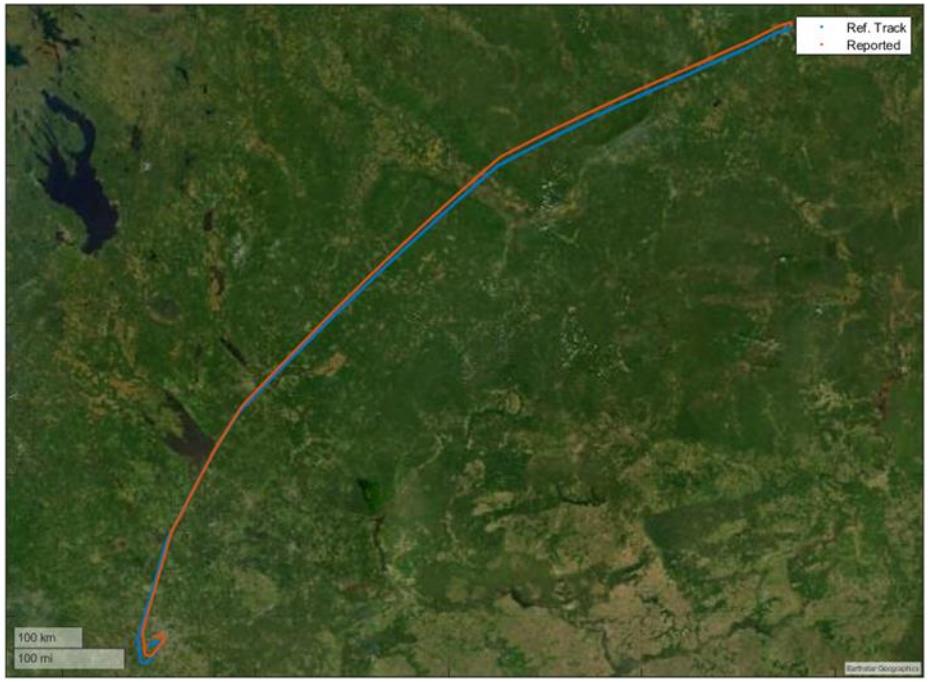
- The intent of the algorithm is to report when an aircraft or report is in the wrong position so that the downstream systems can remove or flag the data
- ADS-B CPR does handle many position outliers, but some can still get through the logic and would form a report
- Independent Position Validation can help mitigate these



Validation Examples

- The internal calculations create a “reference track” that is used for distance calculations
- In this case we identified an aircraft that was reporting an offset position where the reference track followed the correct flight path





Thank You

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