Supporting
European
Aviation

EUROCONTROL

Advanced RAIM

Foundation for robust DFMC GNSS

Gerhard Berz
ICAO Navigation Systems Panel, ARAIM SARPs ad-hoc group Rapporteur
2-4 September 2026, Lima, Peru
gerhard.berz@eurocontrol.int
With contributions from Stanford University, FAA and EU Space Program Agency

FOUNDING MEMBER SESAR JOINT UNDERTAKING

NETWORK MANAGER

Starting Point: ABAS / RAIM (GPS L1)

3.7.3.3 *Aircraft-based augmentation system (ABAS)*

3.7.3.3.1 *Performance*. The ABAS function combined with one or more of the other GNSS elements and both a fault-free GNSS receiver and fault-free aircraft system used for the ABAS function shall meet the requirements for accuracy, integrity, continuity and availability as stated in 3.7.2.4.

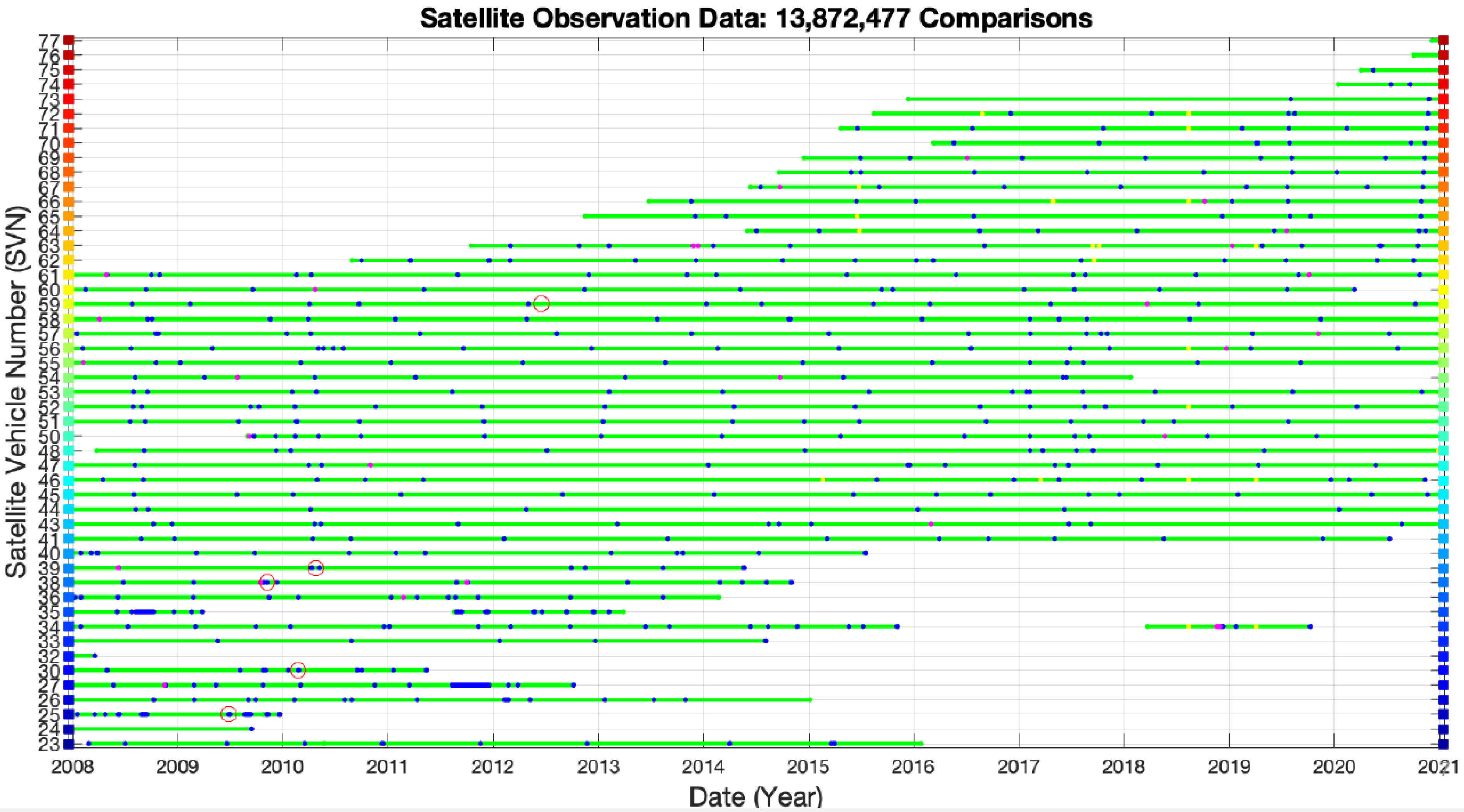
Table 3.7.2.4-1 Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999

- Simplest version of ABAS is GPS RAIM based on FAA TSO C129A (RTCA DO-208)
  - Essential component of majority of Air Transport operations today
  - Drawbacks: Dependence, Vulnerabilities, Lack of Clarity / Transparency

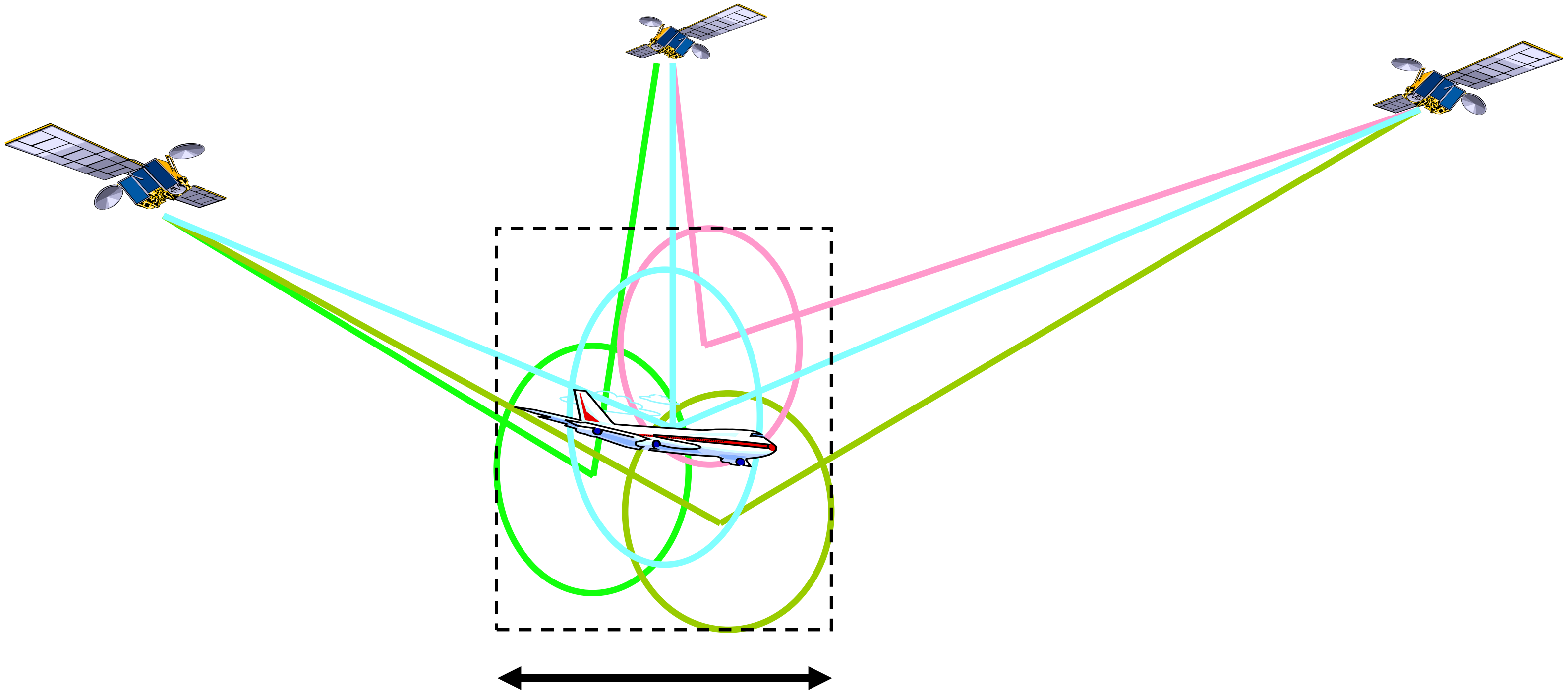
Impressive Service Quality for Many Years!

GPS Performance Summary



What is Receiver Autonomous Integrity Monitoring?

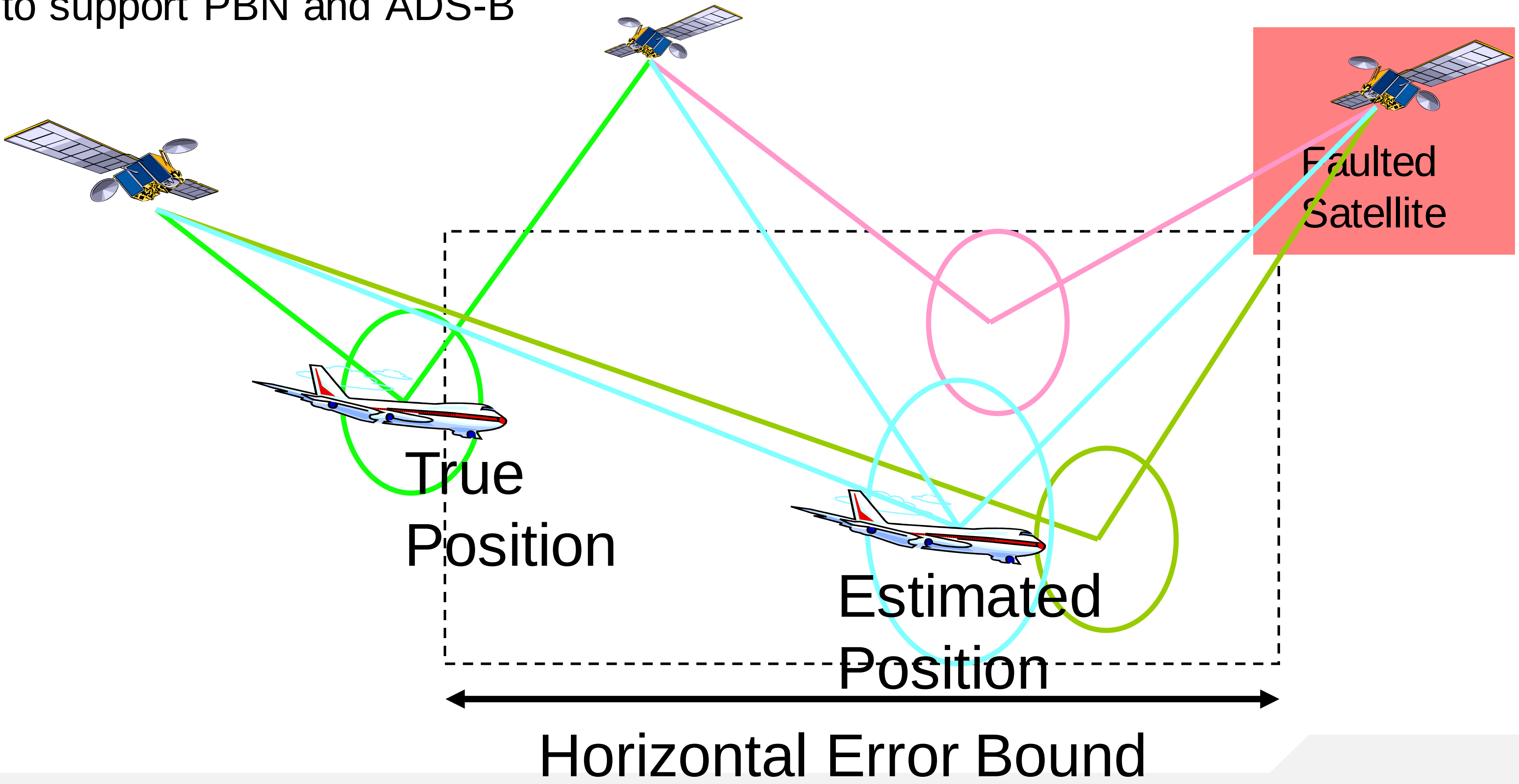
- An algorithm internal to the GNSS receiver
- It takes advantage of the fact that more satellites are received than necessary to compute a position ➔ enables cross-checking of sub-solutions against each other



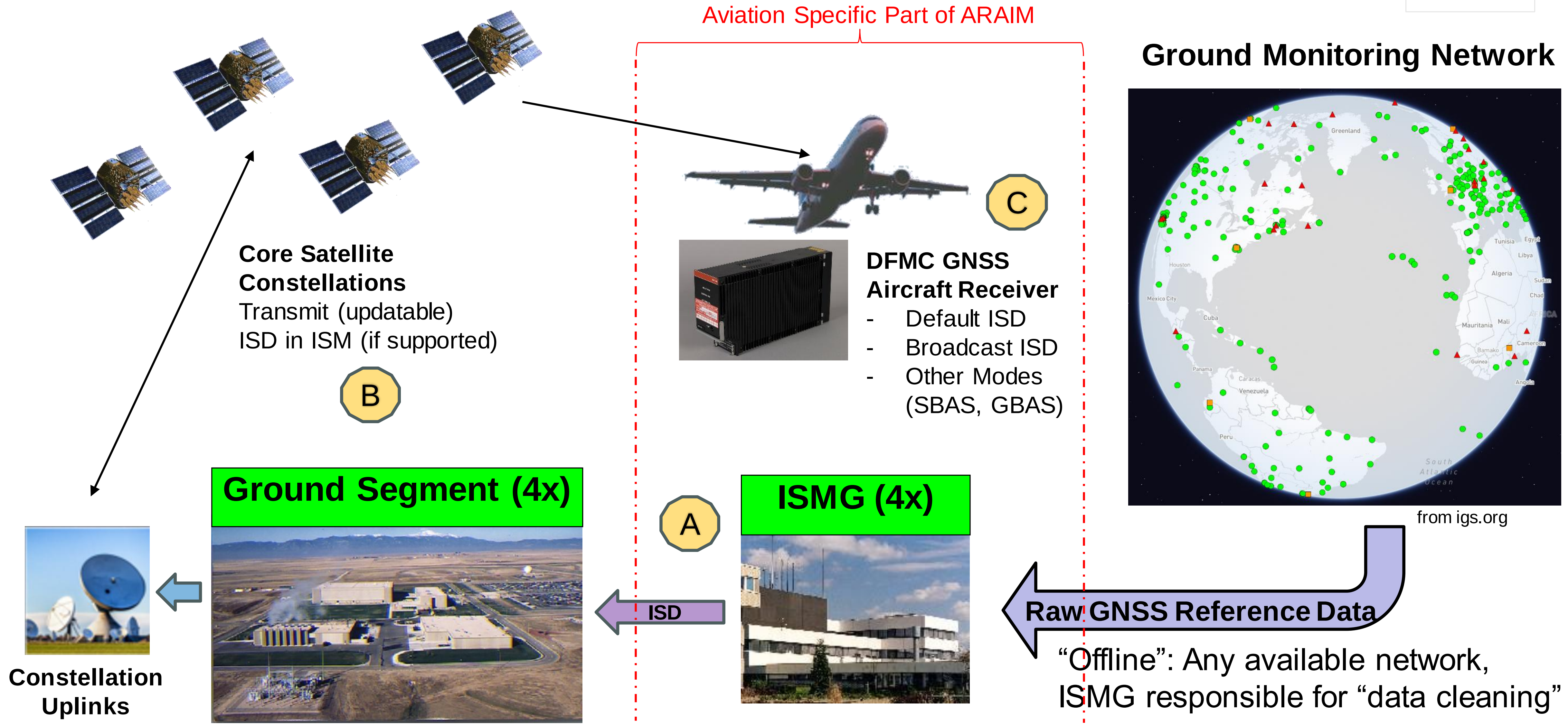
Horizontal Error Bound

What is RAIM?

- Provides WGS-84 Position plus a bound of the horizontal position error
- Can detect and [exclude] individual satellite faults (Fault Detection and Exclusion, FDE)
- Necessary to support PBN and ADS-B



Overview of the ARAIM System



ARAIM Benefits Roadmap

- ARAIM likely to be only future GNSS Augmentation with redundant modes (single frequency or single constellation)
- Incremental Development
  - Current H-ARAIM, Service Type A with default ISM supports performance data collection to build up to:
  - V-ARAIM, Service Type B, enabler for AR37-11 globally

	GPS	GPS + GNSS 2	GPS + GNSS 2 + GNSS 3
Single frequency L1	Good coverage of RNP0.3 with RAIM	Robust worldwide coverage of RNP0.1 with ARAIM	Robust worldwide coverage of RNP0.1 with ARAIM
Dual frequency L1+L5	Good coverage of RNP0.1 with RAIM	Worldwide coverage of LPV 200 with ARAIM	Robust Worldwide coverage of LPV 200 with ARAIM

Note: RNP 0.1 is not a currently defined PBN Navigation Specification per Doc 9613, PBN Manual

ARAIM Development by EU/US WG-C: Milestone Reports

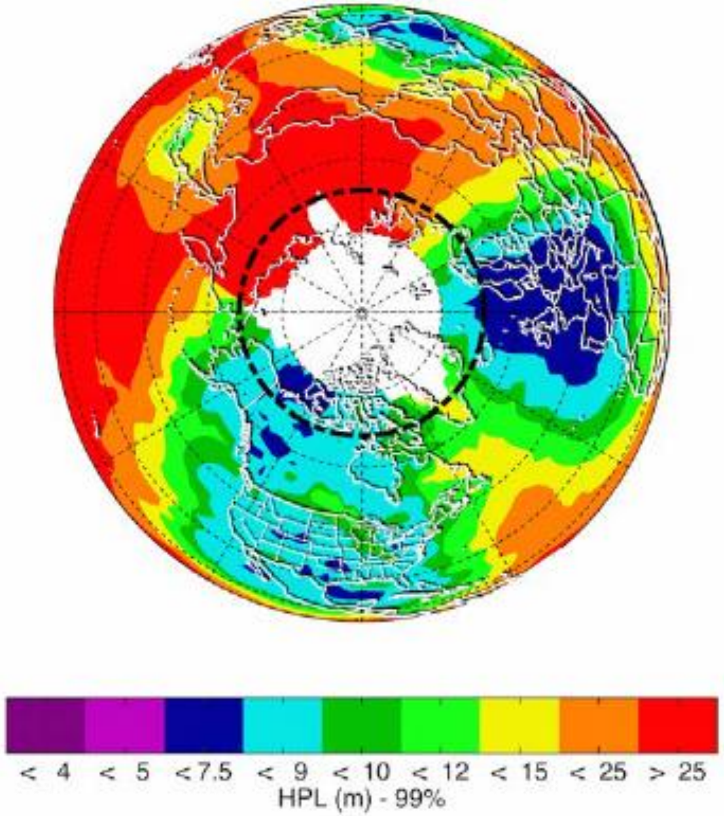


Figure 8: HPL for the Arctic Region Based on Dual Frequency GPS Augmented by WAAS + EGNOS MSAS

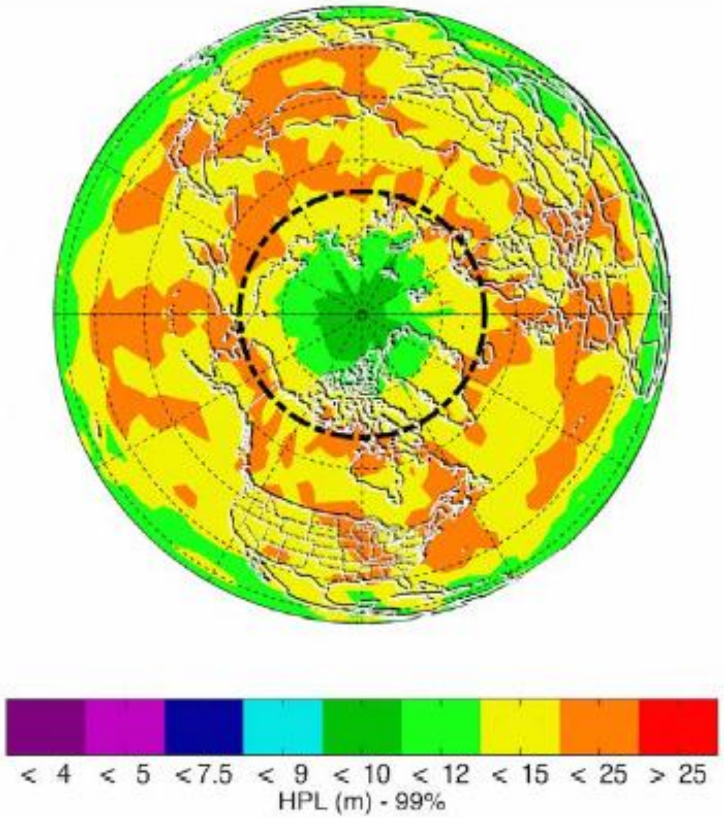
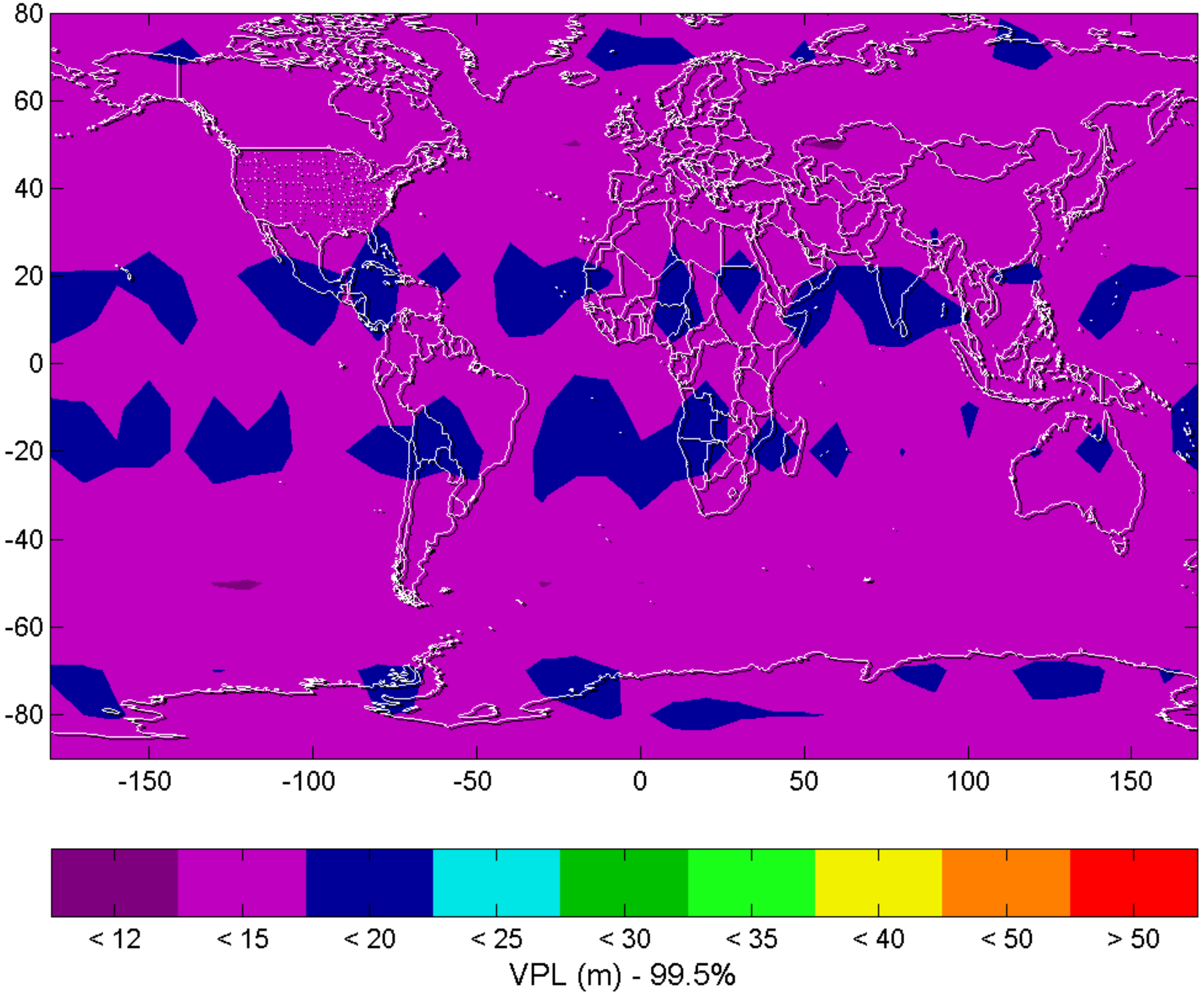


Figure 9: HPL for the Arctic Based on ARAIM with Dual Frequency GPS + Galileo

ARAIM Vertical Protection Level Map: Three constellations (Galileo 27 + GPS 24 + GLONASS 24)



$P_{const} = 10^{-4}$
$P_{sat} = 10^{-5}$

URA = .75 m
Bias = .75 m

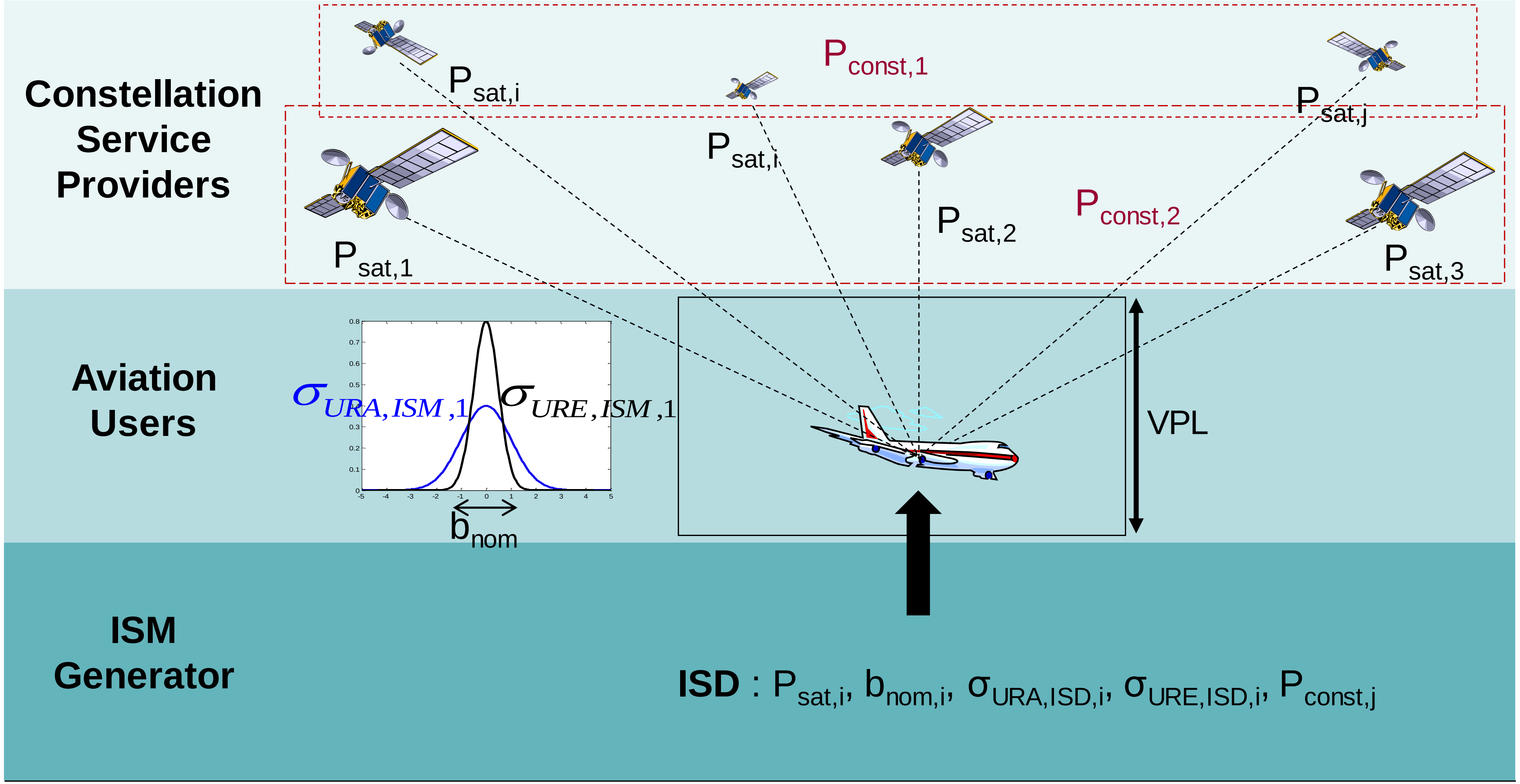
code available at waas.stanford.edu

Integrity Approach

Constellation Service Providers	Service history	Service Performance Commitments	Communication between CSP and ISMG
Aviation Users	Receiver safeguards (beyond residual check: spacing ephemeris updates)		Margin in error models
ISM Generator	Offline monitoring (30 days)		Margin in ISM

Blanch, J., Walter, T., Enge, P., Wallner, S., Fernandez, F., Dellago, R., Ioannides, R., Pervan, B., Hernandez, I., Belabbas, B., Spletter, A., and Rippl, M., “Critical Elements for Multi-Constellation Advanced RAIM for Vertical Guidance,” *NAVIGATION*, Vol. 60, No. 1, Spring 2013, pp. 53-69.

Integrity Support Message



Blanch, J., Walter, T., Enge, P., Wallner, S., Fernandez, F., Dellago, R., Ioannides, R., Pervan, B., Hernandez, I., Belabbas, B., Spletter, A., and Rippl, M., "Critical Elements for Multi-Constellation Advanced RAIM for Vertical Guidance," *NAVIGATION*, Vol. 60, No. 1, Spring 2013, pp. 53-69.

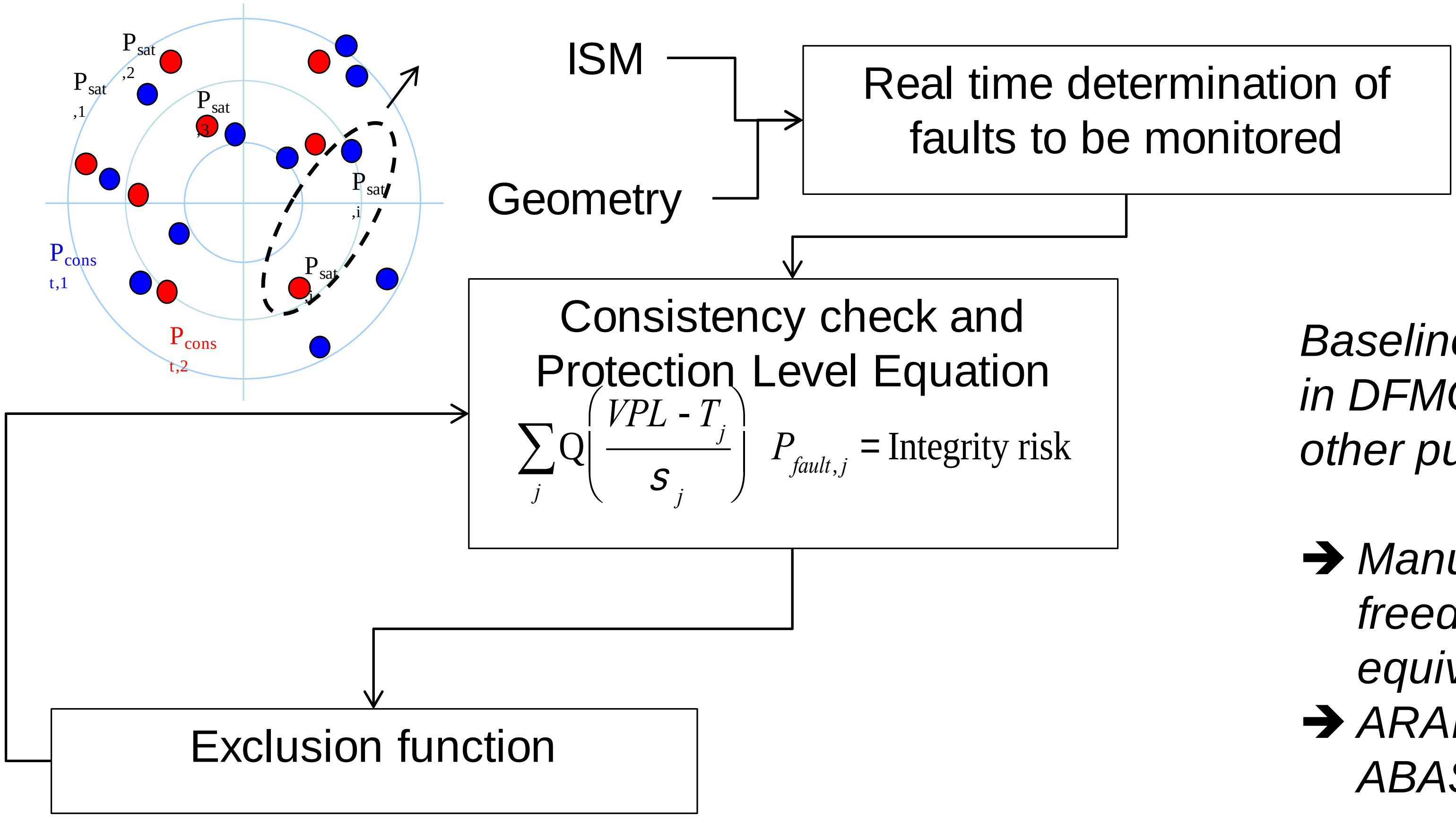
Positioning Threats

ISD

	Nominal	Narrow fault	Wide fault
1-Clock and Ephemeris	Orbit/clock estimation and prediction and broadcast limits	Includes clock runoffs, bad ephemeris, unflagged manoeuvres	Erroneous EOPP, inadequate manned ops, ground-inherent failures
2-Signal Deformation	Nominal differences in signals due to RF components, filters, and antennas waveform distortion $\sigma_{URA,i}$	Failures in satellite payload signal generation components. Faulted signal model as described in ICAO	N/A
3-Code-Carrier Incoherence	e.g. incoherence observed in IIF L5 signal or GEO L1 signals $b_{nom,i}$	e.g. incoherence observed in IIF L5 signal or GEO L1 signals $P_{sat,i}$	N/A $P_{const,j}$
4-IFB	Delay differences in satellite payload signal paths	Delay differences in satellite payload signal paths TBC	N/A
5-Satellite Antenna Bias	Look-angle dependent biases caused at satellite antennas	Look-angle dependent biases caused at satellite antennas	N/A
6-Ionosphere	N/A	Scintillation	Multiple scintillations at solar storms
7-Troposphere	Nominal troposphere error (after applying SBAS MOPS model for tropo correction) $\sigma_{tropo,i}$	N/A	N/A
8-Receiver Noise and Multipath	Nominal noise and multipath terms in airborne model (TBC Gailleo BOC(1,1) and L5/E5a) $\sigma_{airborne,i}$	e.g.: receiver tracking failure or multipath from onboard reflector. TBC	e.g.: receiver tracking multiple failure or multipath from onboard reflector. TBC

From: Working Group C, ARAIM Technical Subgroup, Interim Report, Issue 1.0, December 19, 2012
http://ec.europa.eu/enterprise/newsroom/cf/_getdocument.cfm?doc_id=7793
http://www.gps.gov/policy/cooperation/europe/2013/working-group-c/ARAIM-report-1.0.pdf

Baseline ARAIM Airborne Algorithm



Baseline Algorithm likely to be included in DFMC GNSS Receiver Standard or other publicly available document

- ➔ *Manufacturers have complete freedom to implement and certify equivalent or better algorithms*
- ➔ *ARAIM can be combined with other ABAS elements such as INS, Baro, etc.*

ARAIM Milestone 1 Report

Blanch, J., Walter, T., Enge, P., Lee,Y., Pervan, B., Rippl, M., Spletter, A. "**Advanced RAIM User Algorithm Description: Integrity Support Message Processing, Fault Detection, Exclusion, and Protection Level Calculation**," *ION GNSS 2012, Nashville, September 2012*

Summary / Conclusions

- It is not possible / not correct to use new constellations & signals with “old RAIM”
- ARAIM improves transparency in constellation service provision
  - Globally harmonized set of parameters to characterize error distribution
  - Expect further harmonization and coordination between the 4 ISM Generator entities
  - Service monitoring is integrated and can easily be relied upon by States which do not operate a core satellite constellation
  - CSP / ISMG separation allows aviation oversight of ISMG, consistent with ANSP principles
- ISD / ISM will be broadcast by CSP: An aviation specific service message will be provided!
  - Initial OPS possible with default ISD linked to SARPs constellation committments
- Service Type A SARPs pave the way for Service Type B
  - Global vertical instrument approach guidance (LPV200 / Cat I)
- ARAIM enables the use of DFMC GNSS while providing redundant modes for robustness
- Ensures interoperability while retaining flexibility / performance-based approach for both service providers and avionics manufacturers

Supporting
European
Aviation

EUROCONTROL

Thank you for your attention!

Questions ?

FOUNDING MEMBER SESAR JOINT UNDERTAKING

NETWORK MANAGER

Advanced RAIM Development Path

Initial Service Type A: ca. 2026
Initial Service Type B: ca. 2030

1. Deploy initial ARAIM capability using Default ISD based on core satellite constellation commitments in SARPs
   - Provides redundant modes for DFMC SBAS
2. Build updateable, broadcast ISD for Service Type A
   - Data collection networks already widely available, reference data being stored
3. Implement DFMC GNSS Receivers
   - Validate ISM interfaces with on orbit ISM
   - Collect H-ARAIM Performance Data, including vertical performance
   - Validate Draft V-ARAIM Performance Requirements
4. Update SARPs and MOPS for ARAIM Service Type B
   - Expected to require broadcast ISD
   - May require more frequent update rates of ISD

ARAIM Path from Default ISD to Broadcast ISD (ca. 2026)

EUROCONTROL

A. ISM Generator (one per constellation)

- Develop offline GNSS Recording and Analysis Network
- Generate ISD (ISD ADD, Algorithm Description Document)
- Transmit ISD to Core Satellite Constellation
- Develop and agree aviation oversight process

B. Core Satellite Constellation (GPS. GLONASS, Galileo, BDS)

- Update ground and space segment to enable ISM data message
- Receive ISD from ISMG, Package and Uplink ISM
- Continue providing ISD not in ISM
- Publish Interface Control Documents for ISD / ISM

Under development for GPS by US and Galileo by EU

C. Aircraft DFMC GNSS Receiver

- Include ARAIM in DFMC GNSS Rx: RTCA/EUROCAE MOPS Standard
- Obtain certification and integrate in aircraft avionics architecture
- Receive, decode and apply ISD

Under development by RTCA SC159 / EUROCAE WG62 and avionics / aircraft OEM

ARAIM Path from Service Type A to B (V-ARAIM, ca. 2030)

A. **ISM Generator (one per constellation)**
   - Develop offline GNSS Recording and Analysis Network
   - Generate ISD (ISD ADD, Algorithm Description Document)
   - Transmit ISD to Core Satellite Constellation
   - Develop and agree aviation oversight process

B. **Core Satellite Constellation (GPS. GLONASS, Galileo, BDS)**
   - Update ground and space segment to enable ISM data message
   - Receive ISD from ISMG, Package and Uplink ISM
   - Continue providing ISD not in ISM
   - Publish Interface Control Documents for ISD / ISM

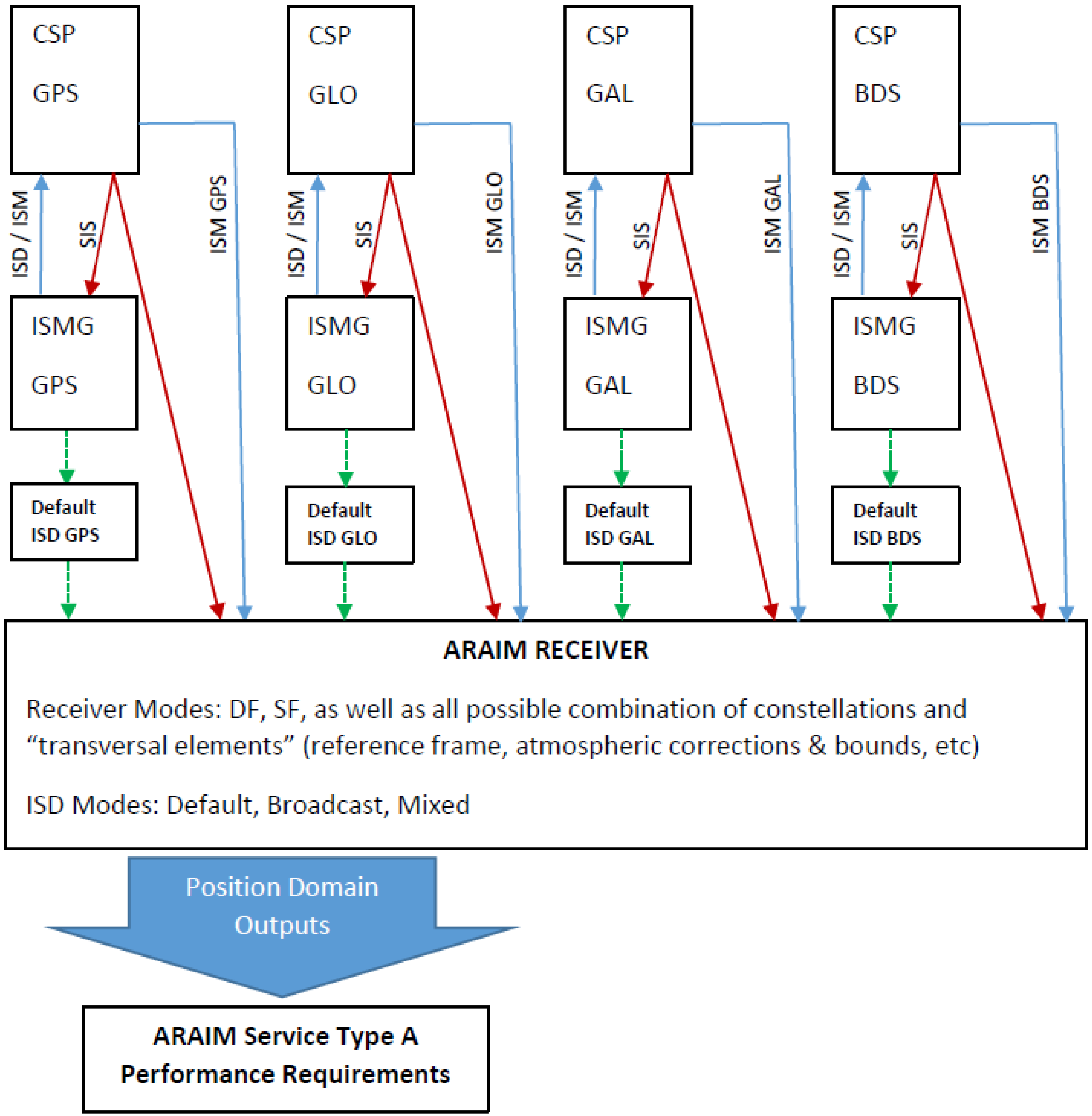
Update algorithms and processes for ST-B, Interfaces remain the same

C. **Aircraft DFMC GNSS Receiver**
   - Include ARAIM in DFMC GNSS Rx: RTCA/EUROCAE MOPS Standard
   - Obtain certification and integrate in aircraft avionics architecture
   - Receive, decode and apply ISD

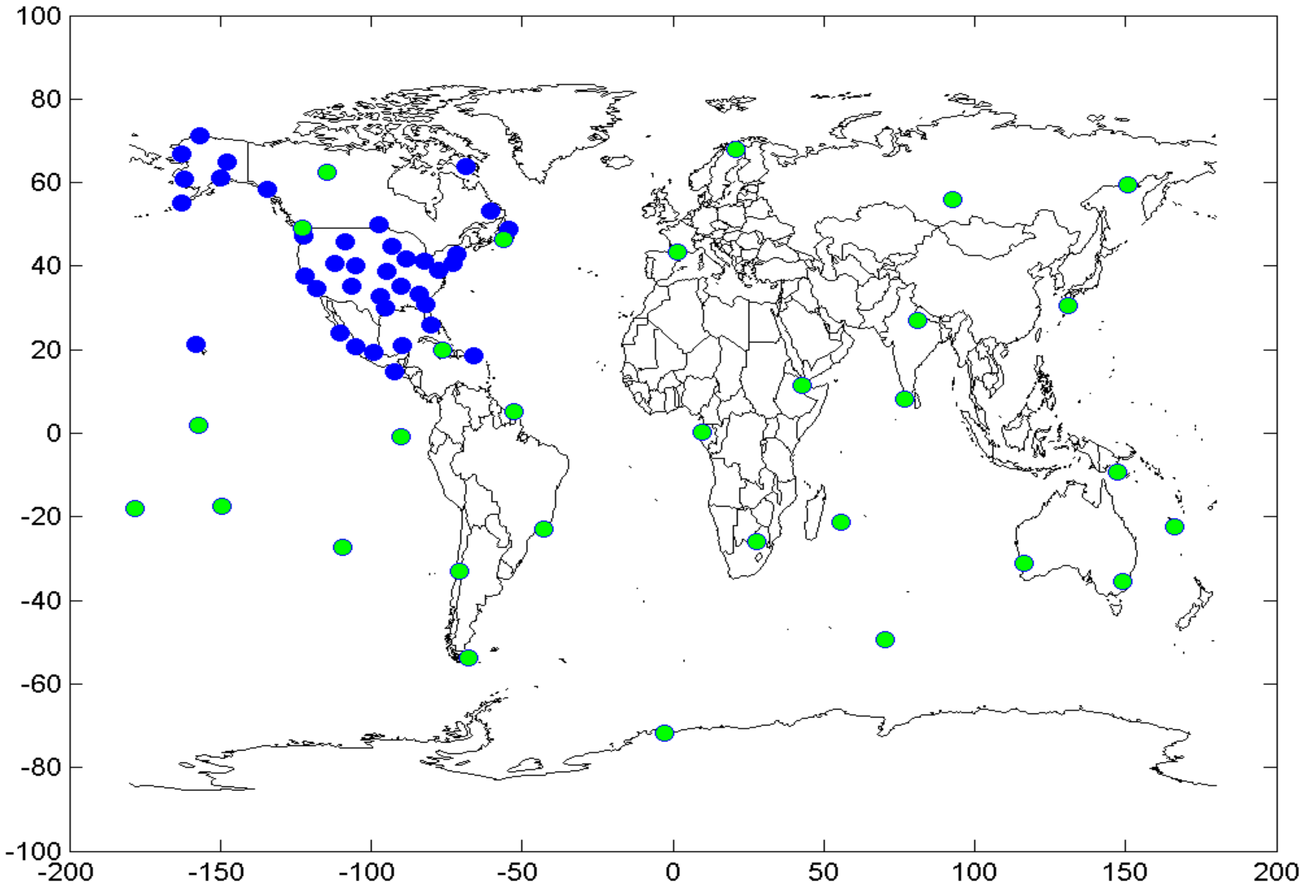
Update algorithms and processes for ST-B, Interfaces remain the same

ARAIM Architecture

- Dynamic Integrity Support Data (ISD)
  - Allows to adapt algorithm performance to core satellite constellation performance
- Initial start of H-ARAIM with Default ISM linked to constellation provider minimum commitments in Annex 10
  - ISD can only improve
- ISD mostly contained in Dedicated Integrity Support Message (ISM) provided by ISM Generator
  - ISMG is a limited ANSP function
  - ISD provided to receiver through constellation navigation messages: no new aircraft interface!



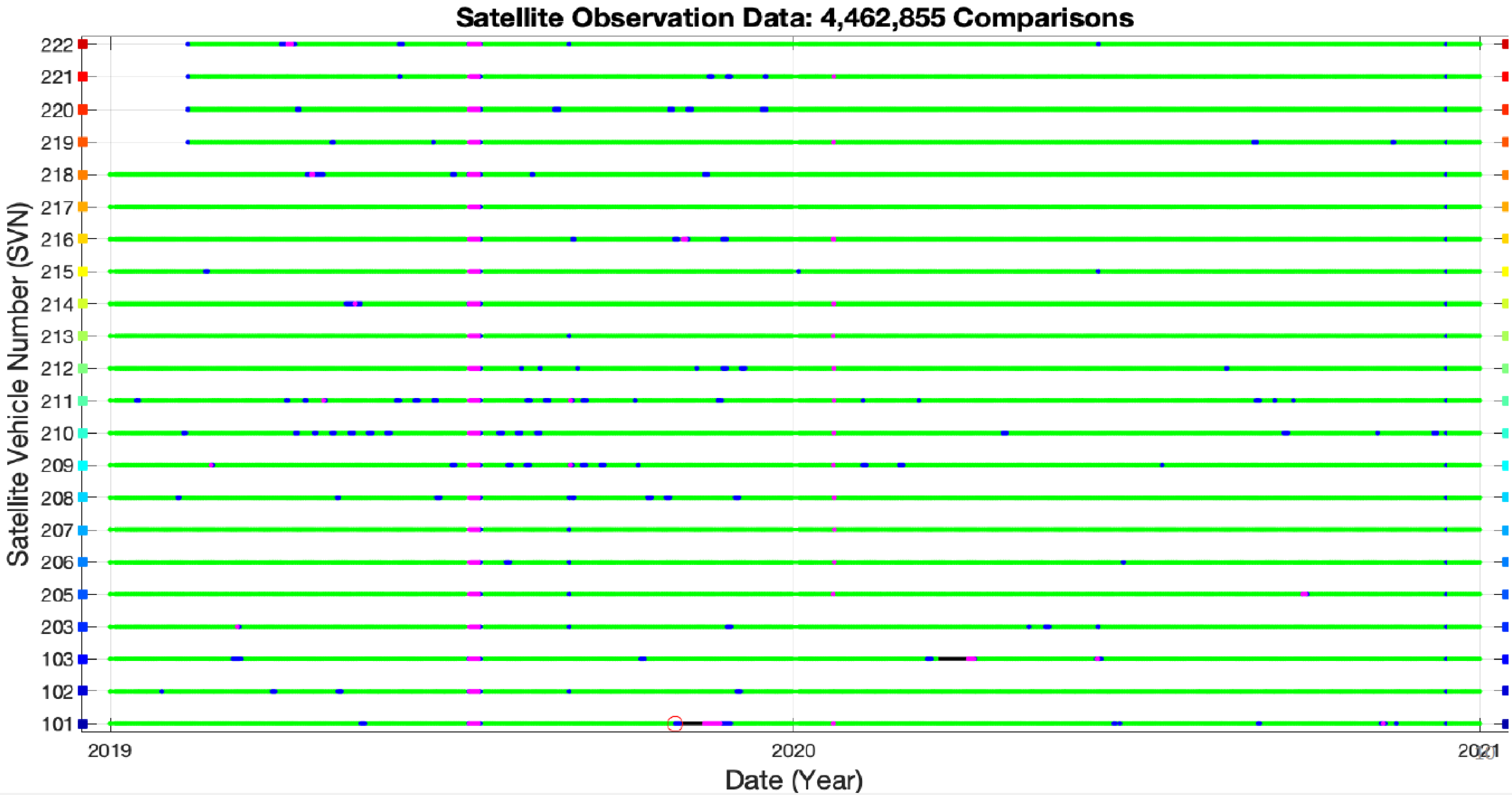
Offline Monitoring to generate ISD



- Based on global sparse network for offline monitoring
  - global, not dedicated
  - reference stations: sufficient to calculate precise orbits
  - subset of network for Signal Deformation and other specialized receiver statistics

- ISM update performed monthly. Analysis similar to:
  - Offline monitoring for WAAS: Gordon, S., Sherrell, C., Potter, B.J., "WAAS Offline Monitoring," *Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010)*, Portland, OR, September 2010, pp. 2021-2030.
  - Performance Assessment Report (WAAS and GPS) by the FAA: Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Report available at http://www.nstb.tc.faa.gov/reports/PAN82_0713.pdf

Galileo Performance Summary



Towards H-ARAIM Operations