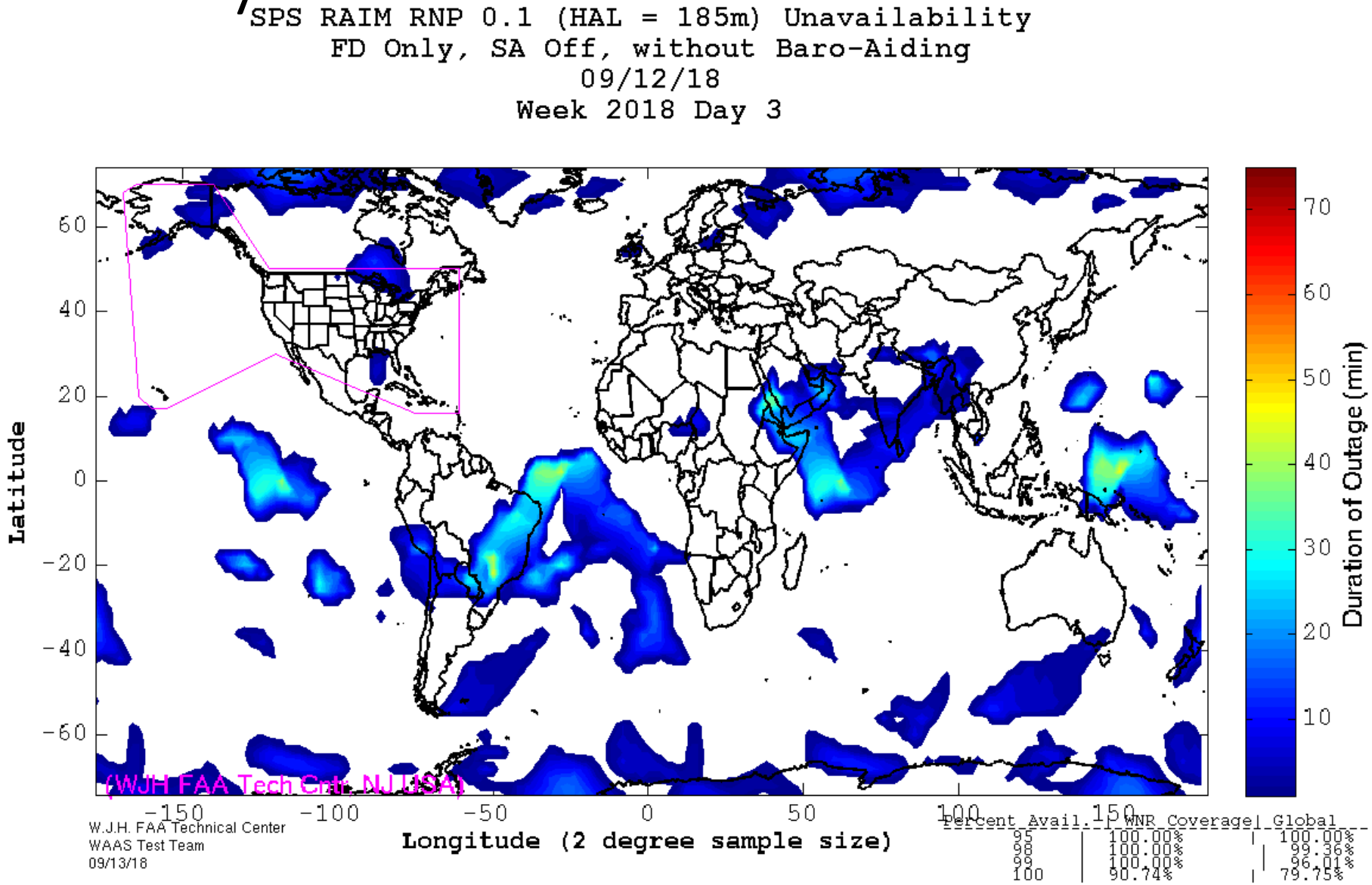
A Proposed Concept of Operations for Advanced Receiver Autonomous Integrity Monitoring (ARAIM)

Juan Blanch, Todd Walter, *Stanford University*
Jason Burns, *FAA*
Ilaria Martini, Juan Pablo Boyero, *European Commission*
Mikael Mabilleau, *European GNSS Agency*
Gerhard Berz, *EUROCONTROL*

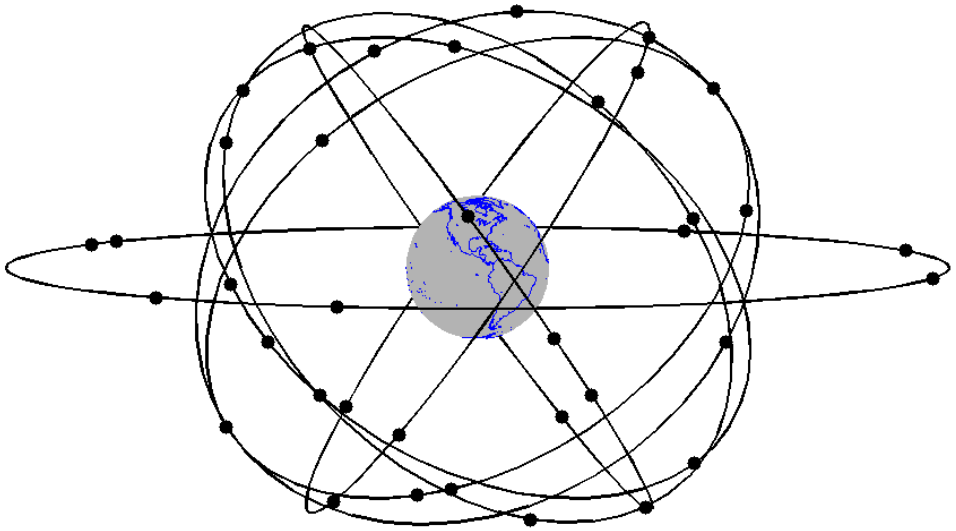
ION GNSS+ 2018

RAIM Today

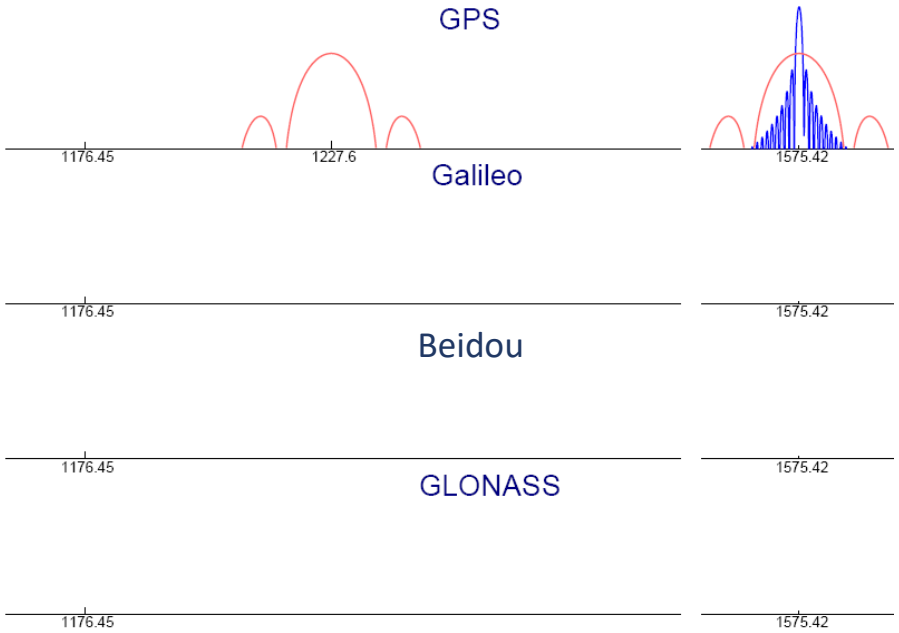

SPS RAIM RNP 0.1 (HAL = 185m) Unavailability
FD Only, SA Off, without Baro-Aiding
09/12/18
Week 2018 Day 3
Latitude
60
40
20
0
-20
-40
-60
-150
-100
-50
0
50
100
150
Longitude (2 degree sample size)
(WJH FAA Tech Cntr, NJ USA)
W.J.H. FAA Technical Center
WAAS Test Team
09/13/18
Duration of Outage (min)
70
60
50
40
30
20
10
Percent Avail. | WNR Coverage | Global
95 | 100.00% | 100.00%
98 | 100.00% | 99.36%
99 | 100.00% | 96.01%
100 | 90.74% | 79.75%

Signals used by aviation in 2018

constellations

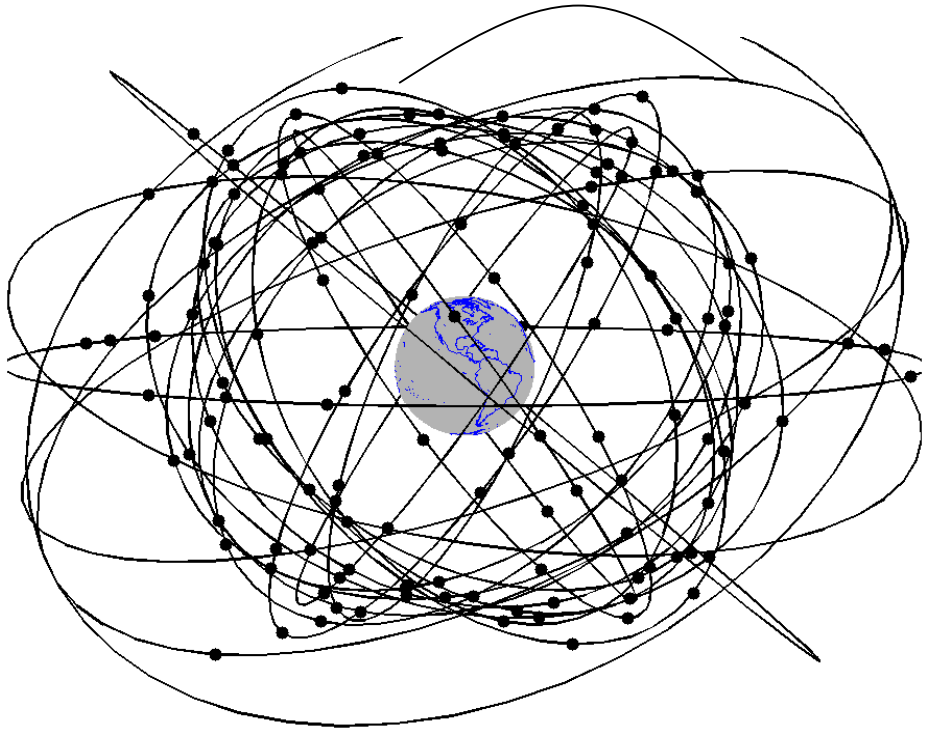


signals

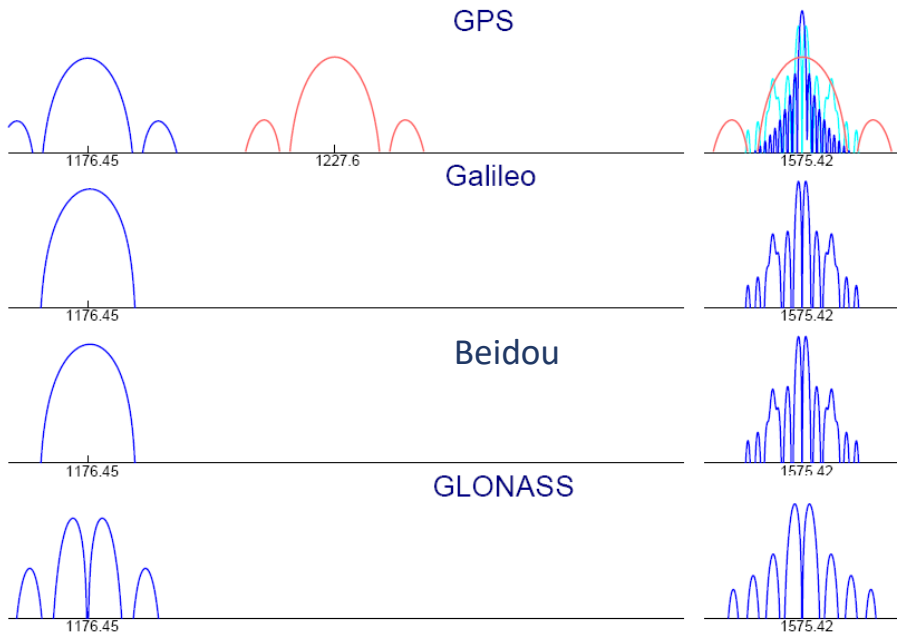


Signals that may be used by aviation users in 2025

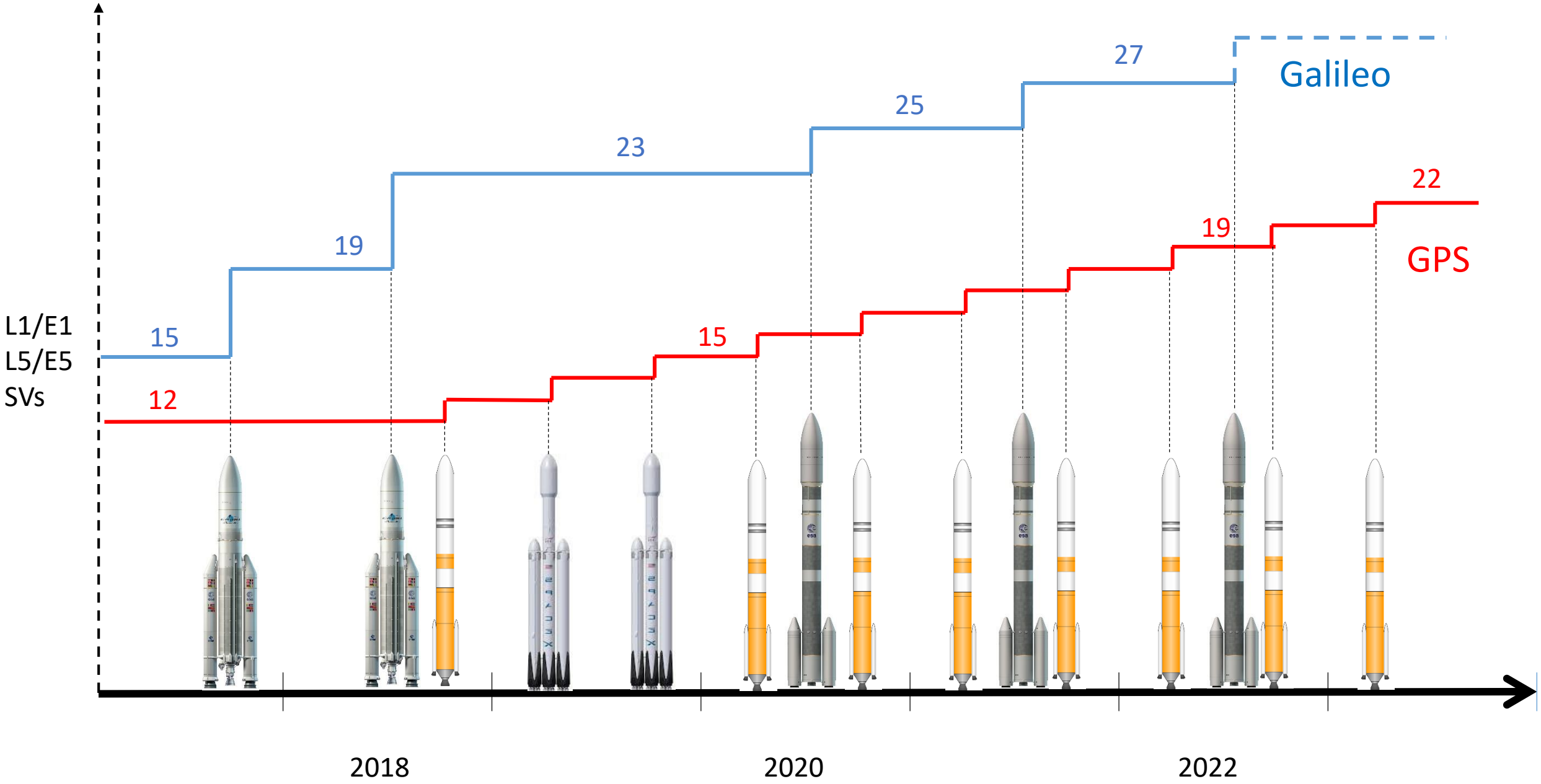
constellations



signals

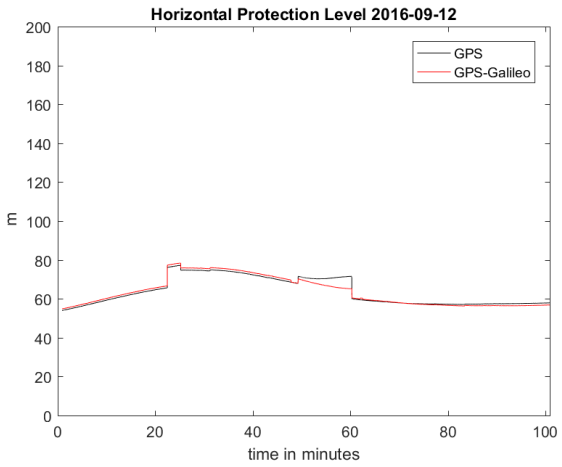


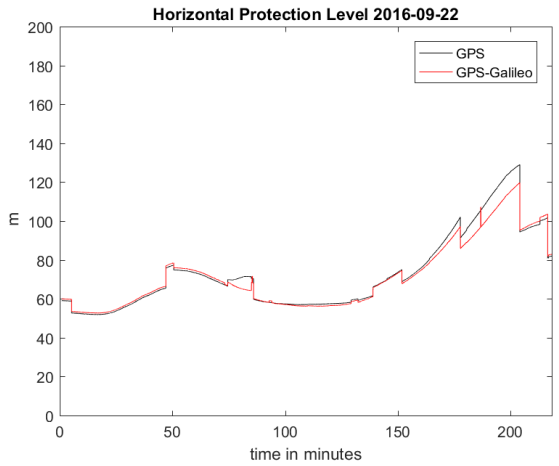
+ better clocks and orbit determination

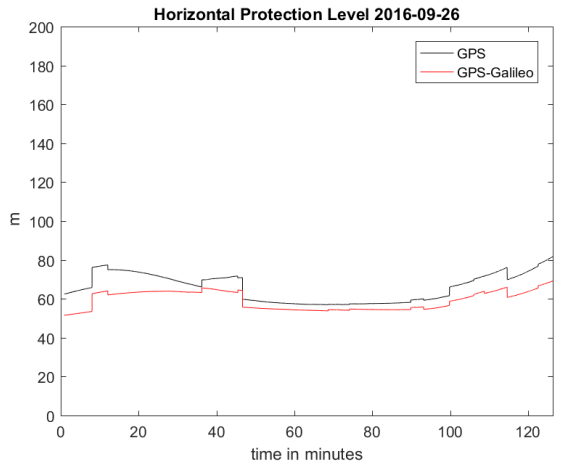


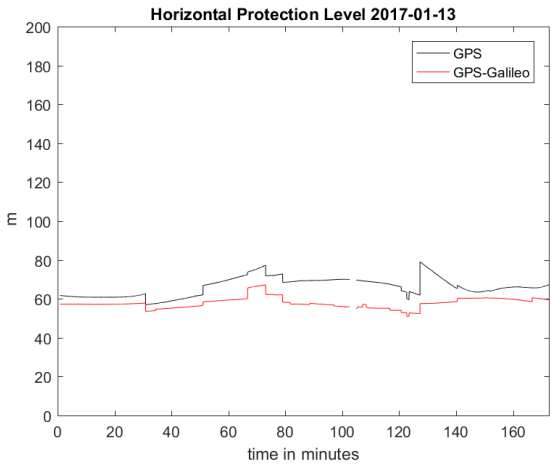
Note: Possible launch schedule based on available data. All satellites shown in this figure are under contract.

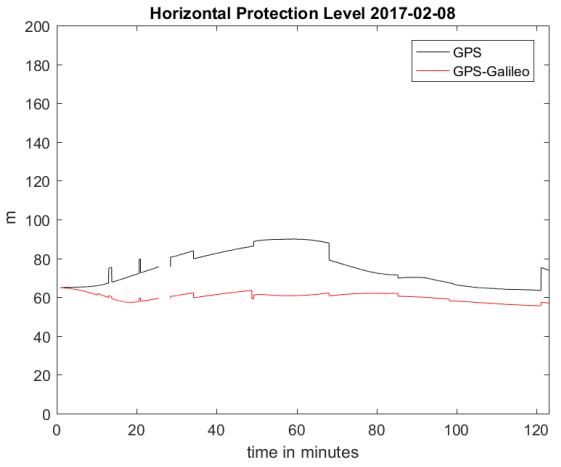
Horizontal ARAIM: Stanford FAA airborne prototype

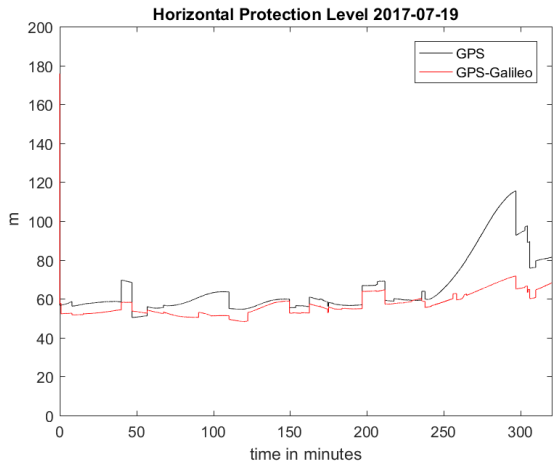


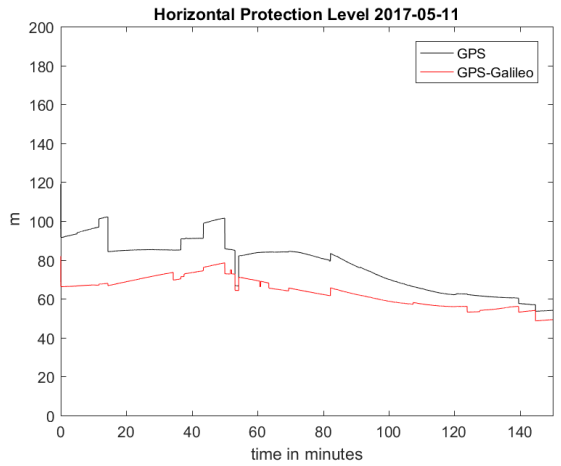


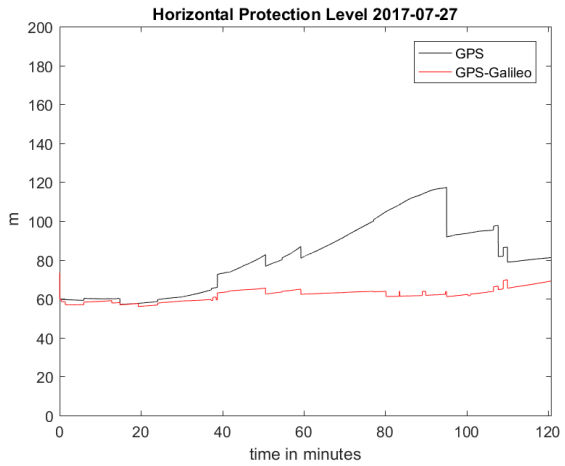




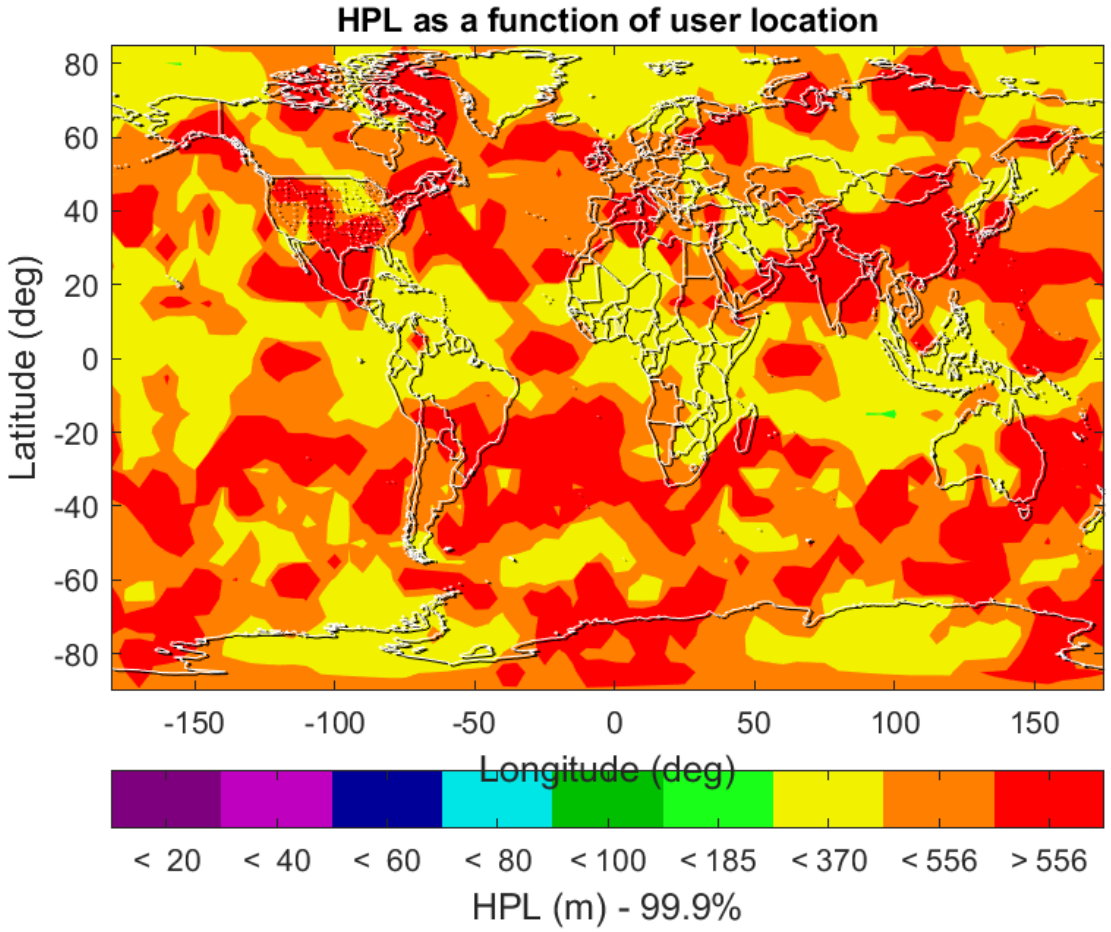




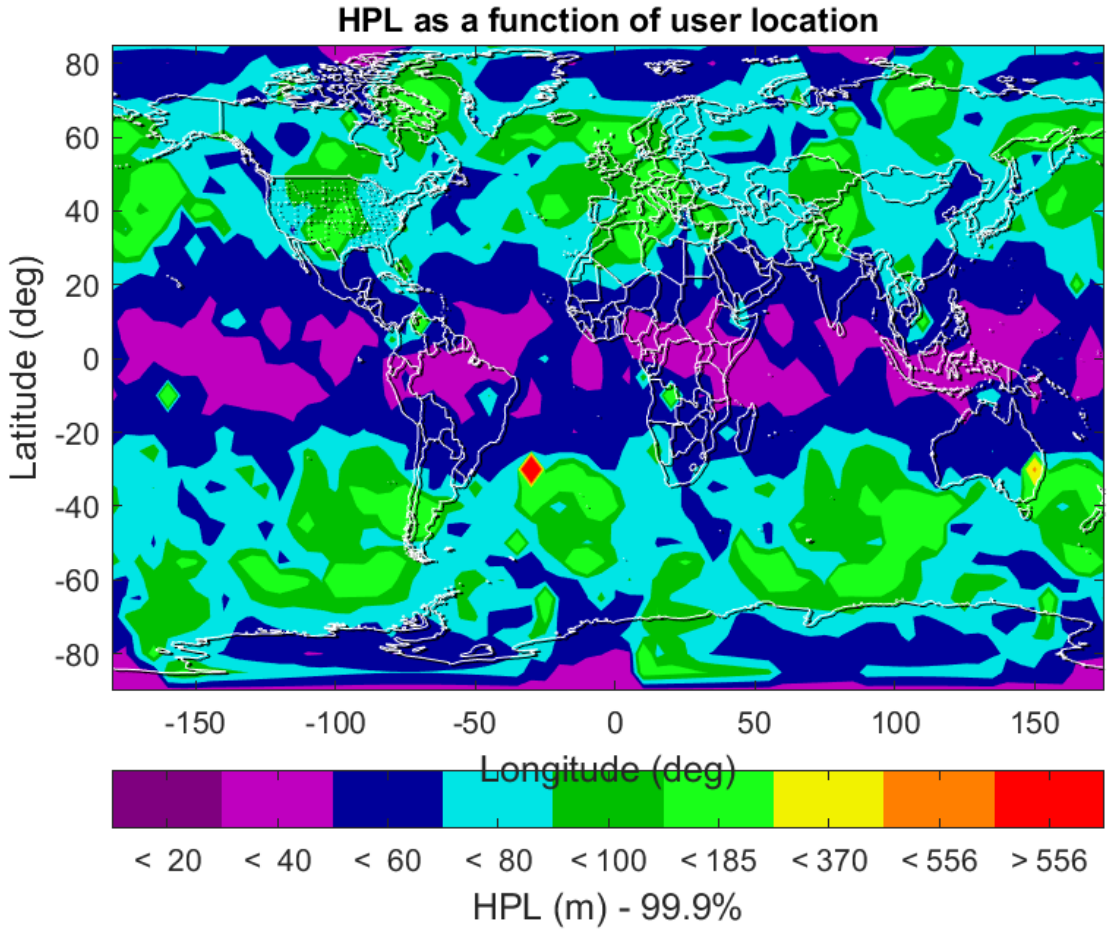




RAIM



ARAIM



Results generated using MAAST for ARAIM available at https://gps.stanford.edu/resources/tools/maast

Target operations

- High availability of RNP0.3
- Suppression of pre-flight check
- ADS-B surveillance requirements

Protection level

$$\sum_{k=0}^{N_{fault\ modes}} p_{fault,k} Q\left(\frac{PL - T_k}{\sigma_k}\right) = P_{HMI}$$

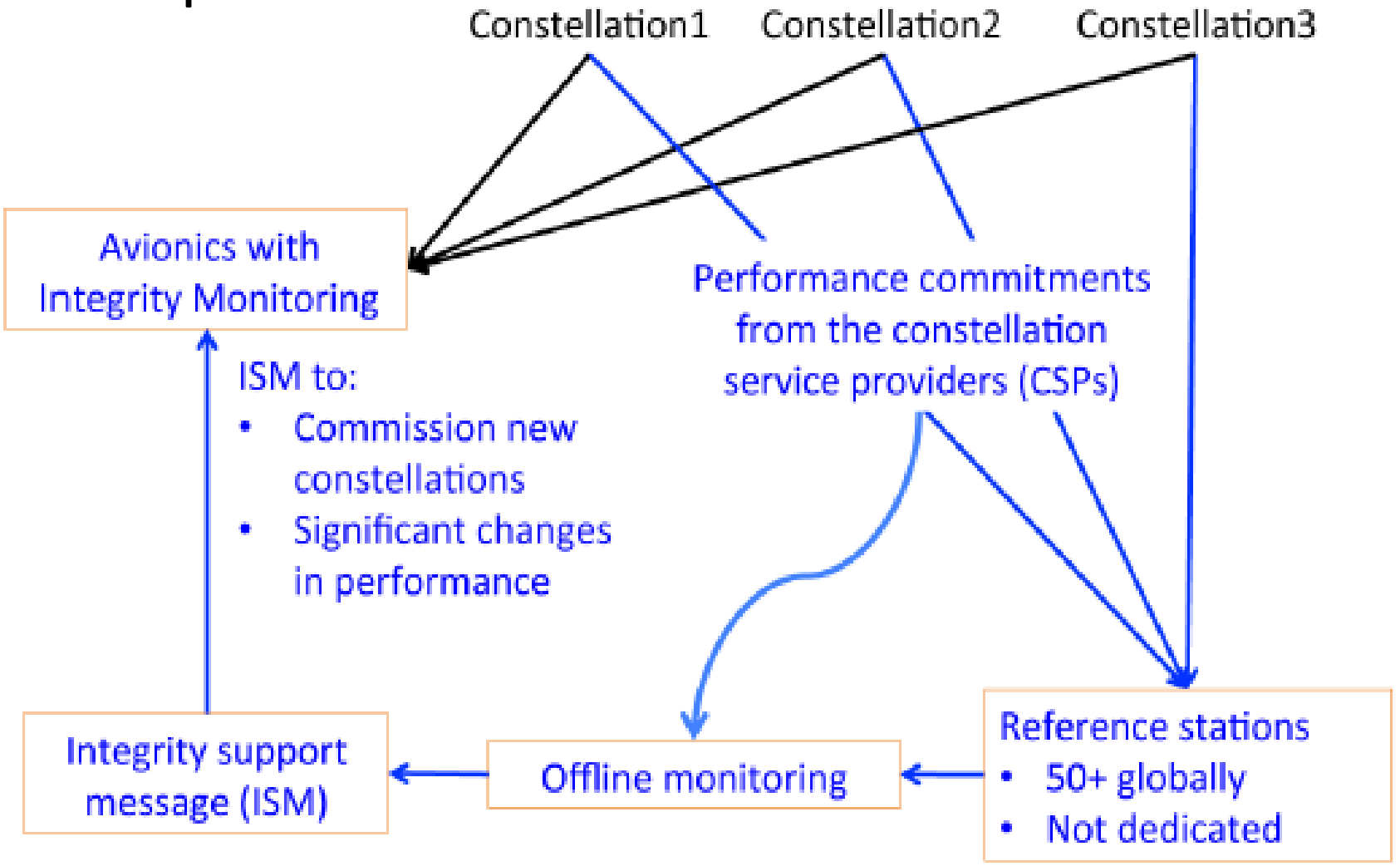
Depends on prior probability of fault

Depends on nominal error model

Integrity Support Message content for ARAIM: Example for horizontal guidance

	GPS	Galileo
$Mask_i$	All 1	All 1
$P_{const,i}$	**10^{-8}**	**10^{-4}**
$P_{sat,j}$	**10^{-5}**	**10^{-4}**
$\alpha_{URA,j}$	**1**	**1**
$\alpha_{URE,j}$	**1**	**1**
$b_{nom,j}$	**0**	**0**

ARAIM concept



Working Group C, ARAIM Technical Subgroup, Milestone 3 Report, February 26, 2016.

Integrity Support Message

- How many ISMs?
- Who determines the ISM?
- How is it determined? According to what rules?
- How is it broadcast?
- How often is it updated?

Stakeholders

- CSP: Constellation Service Provider
- ISM generator
- ANSP: Air Navigation Service Provider
- CAA: Civil Aviation Authority
- ICAO: International Civil Aviation Organization
- Receiver manufacturers
- Air frame manufacturers
- Airlines

ISM origin

- Each GNSS constellation included in the ARAIM solution would have **one set of ISM parameters per level of criticality**.

- This set of parameters would be based on:
  - the **Constellation Service Provider (CSP) commitments**, and according to the ISM standards defined in ICAO SARPs Annex 10
  - **service history and offline monitoring**

- There would be a close coordination between the CSP, ANSP, the ISM generator, and the associated state CAA regulator.

Constellation provider commitments

GLOBAL POSITIONING SYSTEM
STANDARD POSITIONING SERVICE
PERFORMANCE STANDARD

Integrity - S

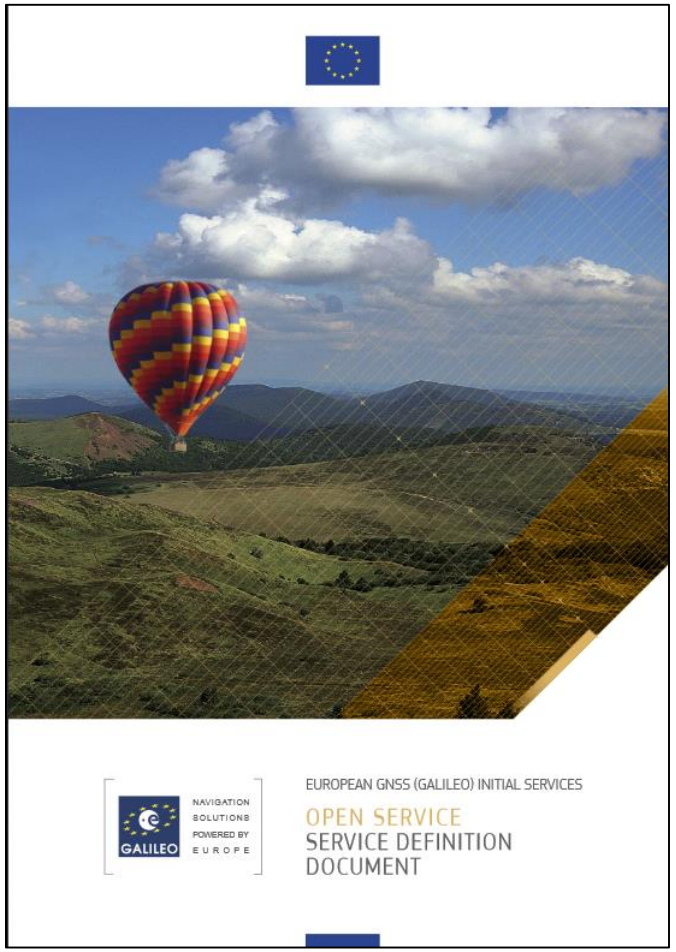
Distribution Statement A: Appr

3.5.1 SPS SIS Instantaneous URE Integrity Standards

The SPS SIS instantaneous URE integrity shall be as specified in Table 3.5-1.

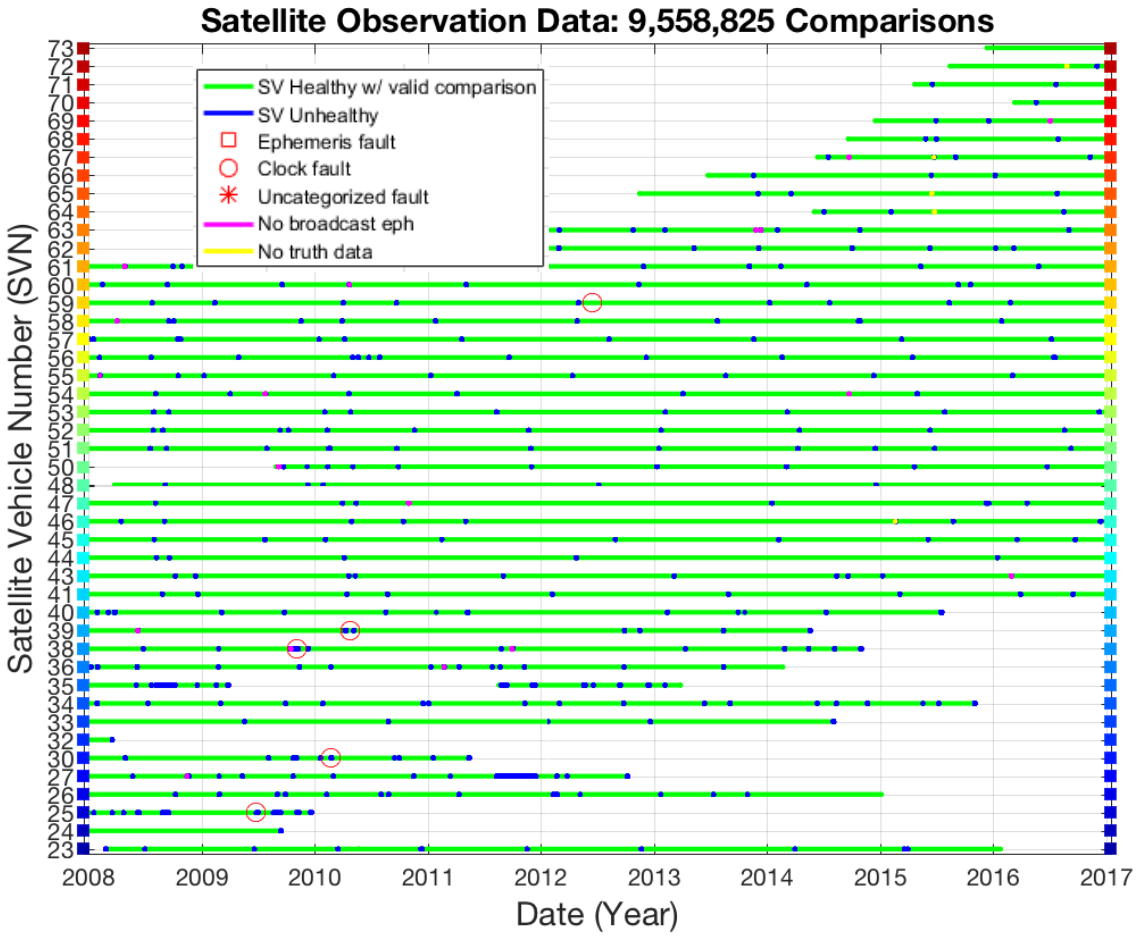
Table 3.5-1. SPS SIS Instantaneous URE Integrity Standards

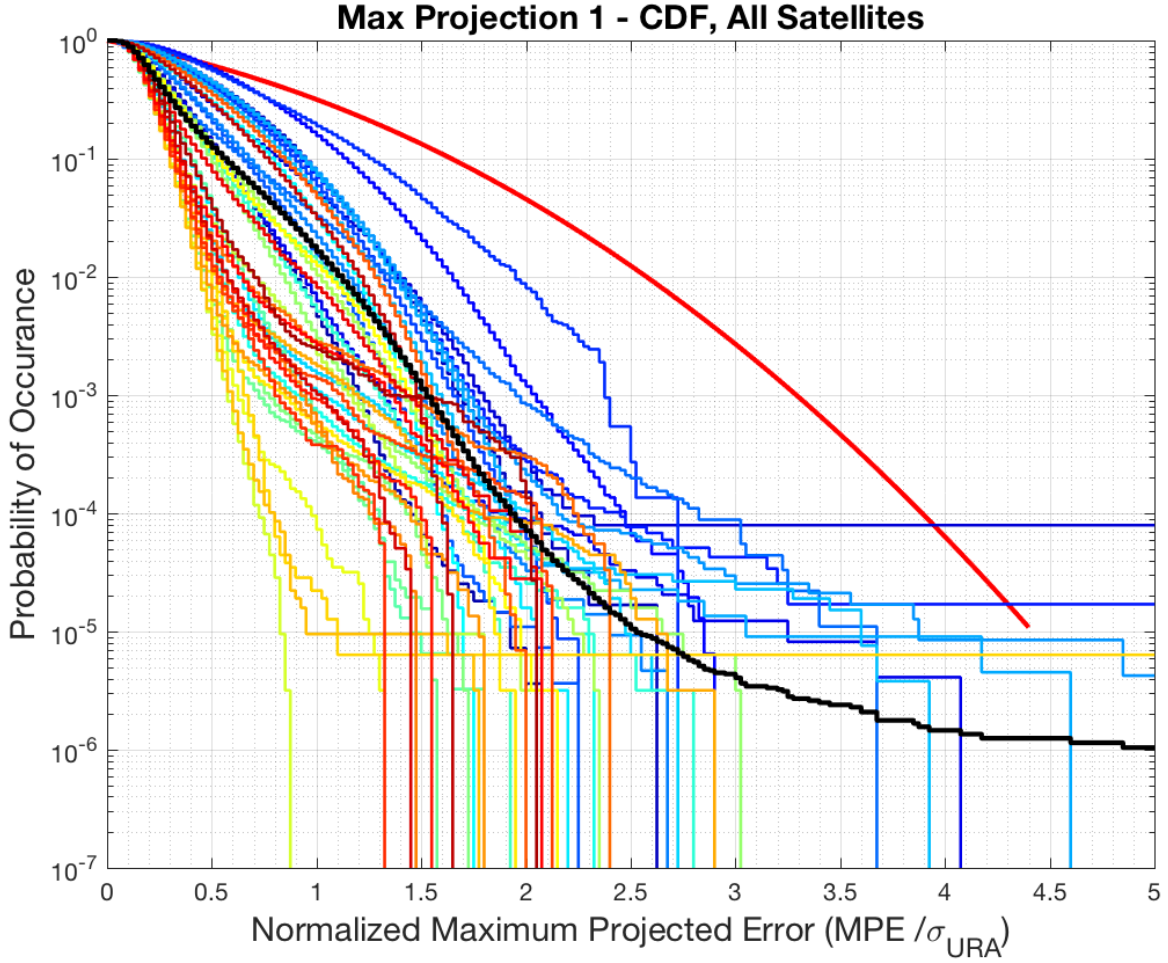
SIS Integrity Standard	Conditions and Constraints
Single-Frequency C/A-Code: • ≤ 1×10^{-5} Probability Over Any Hour of the SPS SIS Instantaneous URE Exceeding the NTE Tolerance Without a Timely Alert during Normal Operations	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite • Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour • Worst case for delayed alert is 6 hours • Neglecting single-frequency ionospheric delay model errors



ISM: Service history and offline monitoring

GPS from 2008 to 2017





Galileo Fault Rates: example

- R_{sat} = 7.2917 x 10^{-5} events/hour
  - Mean fault duration: 3.683 hours
  - **P_{sat} = 2.685 x 10^{-4}**
  - 0 events in 2018
- R_{const} = 1.8339 x 10^{-4} events/hour
  - Mean fault duration: 4.292 hours
  - **P_{const} = 7.871 x 10^{-4}**
  - 2 events in 24 hours on May 14-15, 2017

Narrow Fault Events

		Start time					
SVN	Duration (hours)	Year	Month	Day	Hour	Min	Sec
101	0.33	2017	5	14	12	55	0
101	8.54	2017	12	26	7	38	0
102	0.75	2017	5	14	11	30	0
203	24.50	2017	6	6	5	50	0
203	1.33	2017	6	8	15	30	0
203	0.01	2017	6	8	16	10	0
205	0.67	2017	1	1	0	10	0
205	1.58	2017	8	7	16	25	0
205	3.58	2017	8	7	23	25	0
205	3.17	2017	11	28	6	41	30
206	0.83	2017	3	7	3	15	0
206	1.33	2017	5	15	0	55	0
211	1.25	2017	5	14	10	0	0

Wide Fault Events

	Start time					
Duration (hours)	Year	Month	Day	Hour	Min	Sec
1.17	2017	5	14	13	30	0
7.42	2017	5	14	17	30	0

Results in this example are <u>not</u> to be taken as indicative on the commitments on H-ARAIM parameters from the Galileo programme (see next slide)

Based on Stanford GPS Lab. Analysis [1].

[1] Walter, T., Blanch, J., Joerger, M., Pervan, B., "Determination of Fault Probabilities for ARAIM," Proceedings of IEEE/ION PLANS 2016, Savannah, GA, April 2016, pp. 451-461.

Galileo Commitments for Horizontal ARAIM

- The Galileo programme has put in place a work plan to derive commitments for Horizontal ARAIM
- Goal of the programme: to provide commitments in line with targets defined in [1]
- Ground segment releases and tuning of the system configuration will make it feasible to ensure commitments at the time of the Full Operational Capability declaration
- Commitments will then be justified and supported by real data analyses and taking into account the final state of the System implementation

[1] Working Group C, ARAIM Technical Subgroup, Milestone 3 Report, February 26, 2016.

ISM Broadcast

- Dissemination means has been decided, but details still need to be determined
- Current plan: ISM sent through GNSS
- Each GNSS sends its own ISM
- Interim option: hardcoded ISM (as in RAIM today)

ISM Broadcast via GNSS: GPS draft MT 38

Table 20-XII. ISM Parameters

Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
GNSS ID	GNSS Constellation ID	4	1	8	see text
P_{const}	Probability of constellation integrity fault	3			see text
P_{sat}	Probability of satellite integrity fault	3			see text
t_{correl}	Correlation time constant	3			see text
$M_{integrity}$	URA multiplier for integrity	3			see text
$M_{accuracy}$	URA multiplier for accuracy	3			see text
$b_{nominal}$	Nominal pseudorange bias	4			see text
Flags	Valid for ARAIM flags	63 x (2)			see text

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.
** See Figure 20-15 for complete bit allocation in Message Type 38.
*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

Still missing important elements:

- Criticality flag
- Time of Applicability or sequence counter

Courtesy of Karl Kovach, Aerospace Corporation

ISM Broadcast via GNSS: Galileo

- Galileo is working on the definition of the ISM message for Horizontal ARAIM

- Approach for the message definition takes into consideration
  - Identifier for the ISM Generator
  - Mask to indicate to which satellites the ISM would apply
  - Possibility to include the parameters for a second constellation (e.g. GPS)

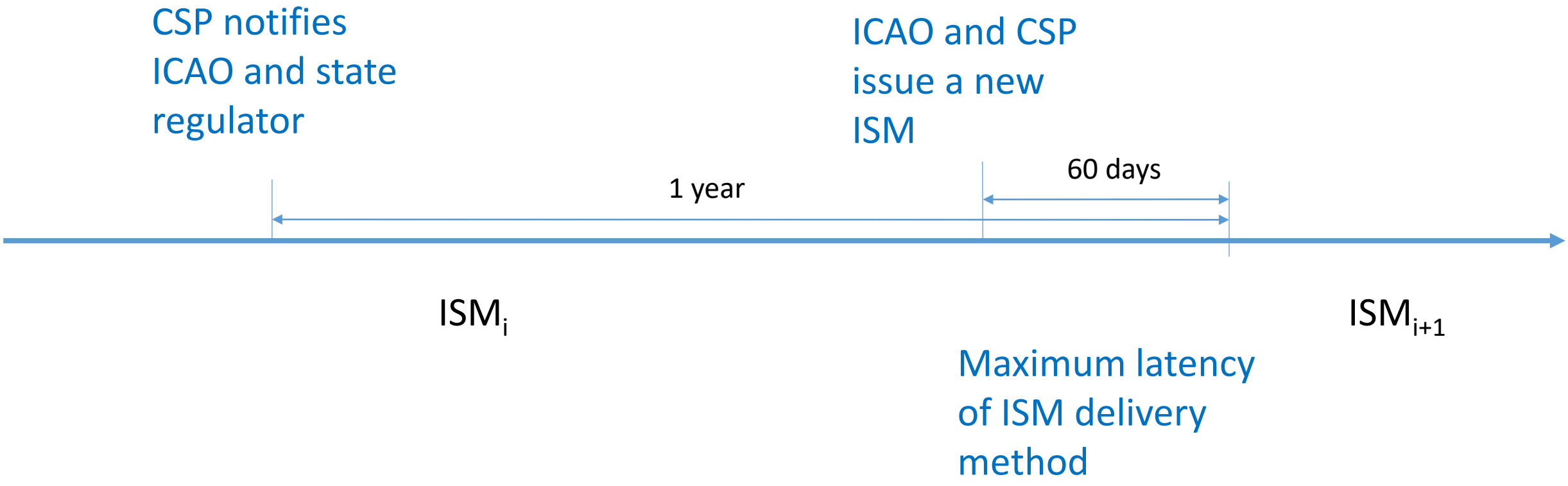
Integrity Support Message: Latency

- RAIM depends on the notion that GPS performance is quasi-static. This would be similar for Horizontal ARAIM.

- ISM should only change if the commitment changes. Commitment changes should be coordinated years in advance.

- Therefore, ISM values should be valid for years after confirmation of the CSP and its commitments.

Notional latency requirements



Receiver requirements

- Advanced RAIM will require significant updates in the receiver requirements.
- These changes derive from the variability of the prior probability of faults and its effect on the monitoring requirements.
- Receiver standards (MOPS) will describe minimum requirements on the fault monitoring as a function of the ISM.
- Receiver standards will not mandate a particular algorithm

Integrity Support Message

- How many? One per constellation (for one level of criticality)
- Who determines it? The CSP, the ANSP, and the associated state CAA regulator
- How is it determined? According to what rules? Based on the commitments and independent monitoring following high level guidelines agreed upon at ICAO
- How is it broadcast? GNSS
- How often is it updated? Only after major changes in constellations

Summary

- Inclusion of new signals in RAIM will dramatically improve performance, enabling operations that are now only available with augmentation or additional sensors

- However, these new signals must be characterized such that the navigation requirements are met

- In this ARAIM concept:
  - One ISM per constellation per level of criticality
  - ISM quasi-static and mostly determined by the CSP commitments (in coordination with an associated CAA)
  - Will be broadcast via GNSS