Progress Update on Multi-constellation Safety-of-Life Activities

Eric Chatre, DG Enterprise and Industry

Ken Alexander, Federal Aviation Administration

International Committee on GNSS - ICG-9

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UNITED NATIONS
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EU-U.S. GNSS Cooperation in WG-C

- Under the auspices of the European Union (EU) and United States (U.S.)

  2004 Agreement on the Promotion, Provision and Use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications,

  the EU and U.S. established Working Group C in 2010:

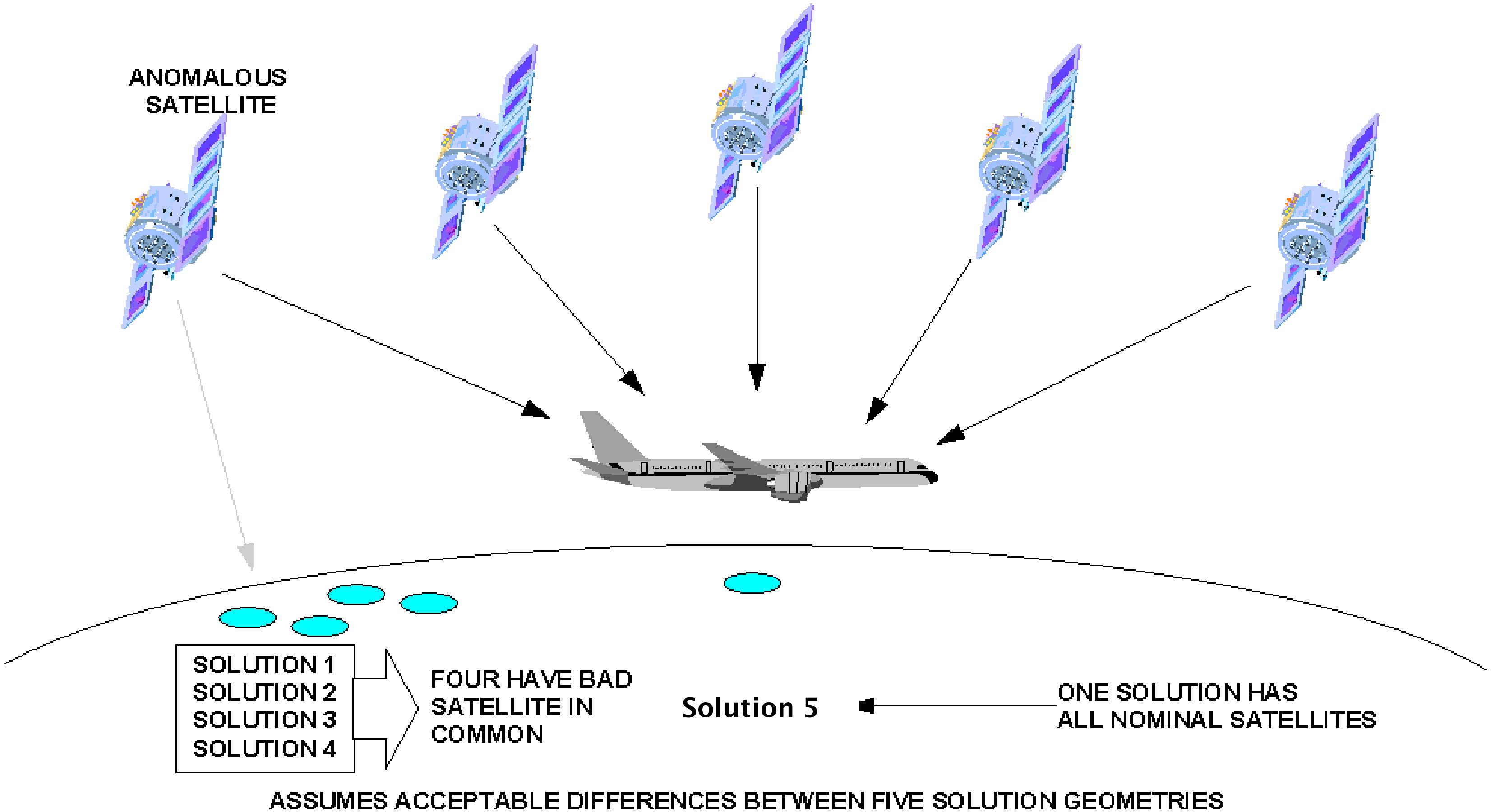
  To promote cooperation on design and development of next generation of civil satellite-based navigation and timing systems

- A key element of the work programme is investigation of candidate concepts for provision of future integrity services

Advanced Receiver Autonomous Integrity Monitor (ARAIM) Study

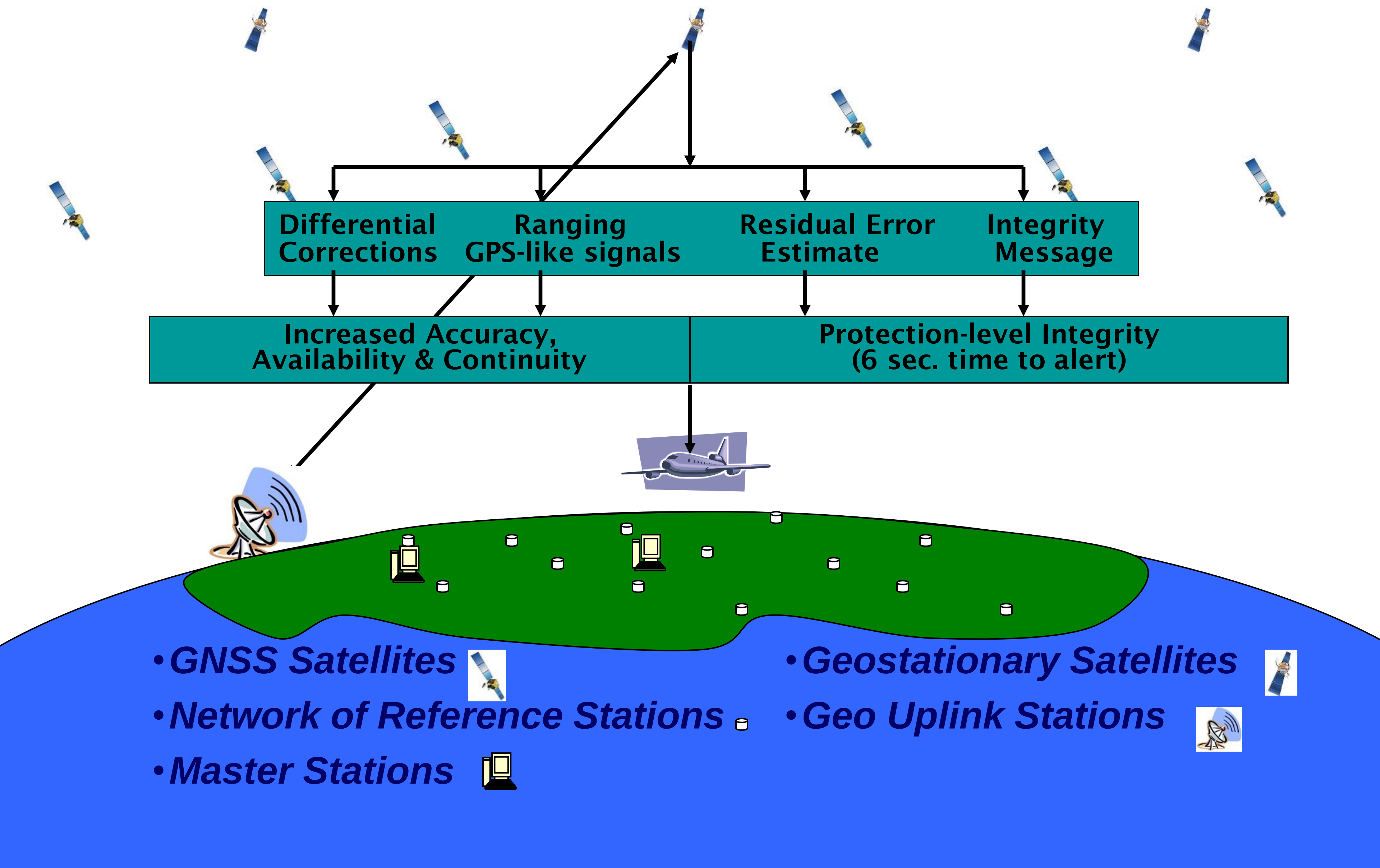
- Define a reference multi-constellation ARAIM concept providing vertical guidance (LPV-200) with worldwide coverage
  - Horizontal Alert Limit with 10-7 integrity < 40m
  - Vertical Alert Limit with 10-7 integrity < 35m
  - RNP 0.3 Reversionary capability (conventional RAIM)
  - Robust against constellation faults & satellite failures
- Investigate ARAIM assumptions, algorithms, and candidate implementation architectures
- Harmonize understanding of concept and architecture options to provide a basis for standardization
- Mature concept and produce final report for consideration and prospective implementation, enabled by:
  - International standards bodies, Provider States, Manufacturers and Aircraft Owners/Operators

Conventional RAIM



- ***Global Reference Stations***
- ***Airborne Consistency Check***
- ***GNSS Broadcast Data***
- ***Master Control Segment***

SBAS Architecture



ARAIM Implementations

- Provides vertical, as well as horizontal, aircraft guidance
- Avionics can compare ranging measurements to different satellites to ensure they are consistent
- The satellites must perform within a certain range of expectations to meet aviation integrity requirements
- Individual aviation authorities may independently monitor satellite performance and could provide an Integrity Support Message (ISM)
- Alternatively, authorities can accept “trusted” ISM from other sources including GNSS provider State
- Given an assumed set of fault modes, responsibility for mitigating each fault can be assigned to aircraft, ground, space segment, or some combination
- Each ARAIM architecture requires an allocation strategy so that each segment can be assessed relative to its goal

KEY ARAIM ARCHITECTURAL PROPERTIES

- Key architectural properties:
  - Bounding methodology (ranging quality, GNSS failures)
  - Communication and computation latency
  - Broadcast methodology
  - Integrity Support Message (ISM) contents
  - Handling of constellation faults
  - Reference network
- Properties are strongly interconnected, so a choice in one area may strongly influence choices in others

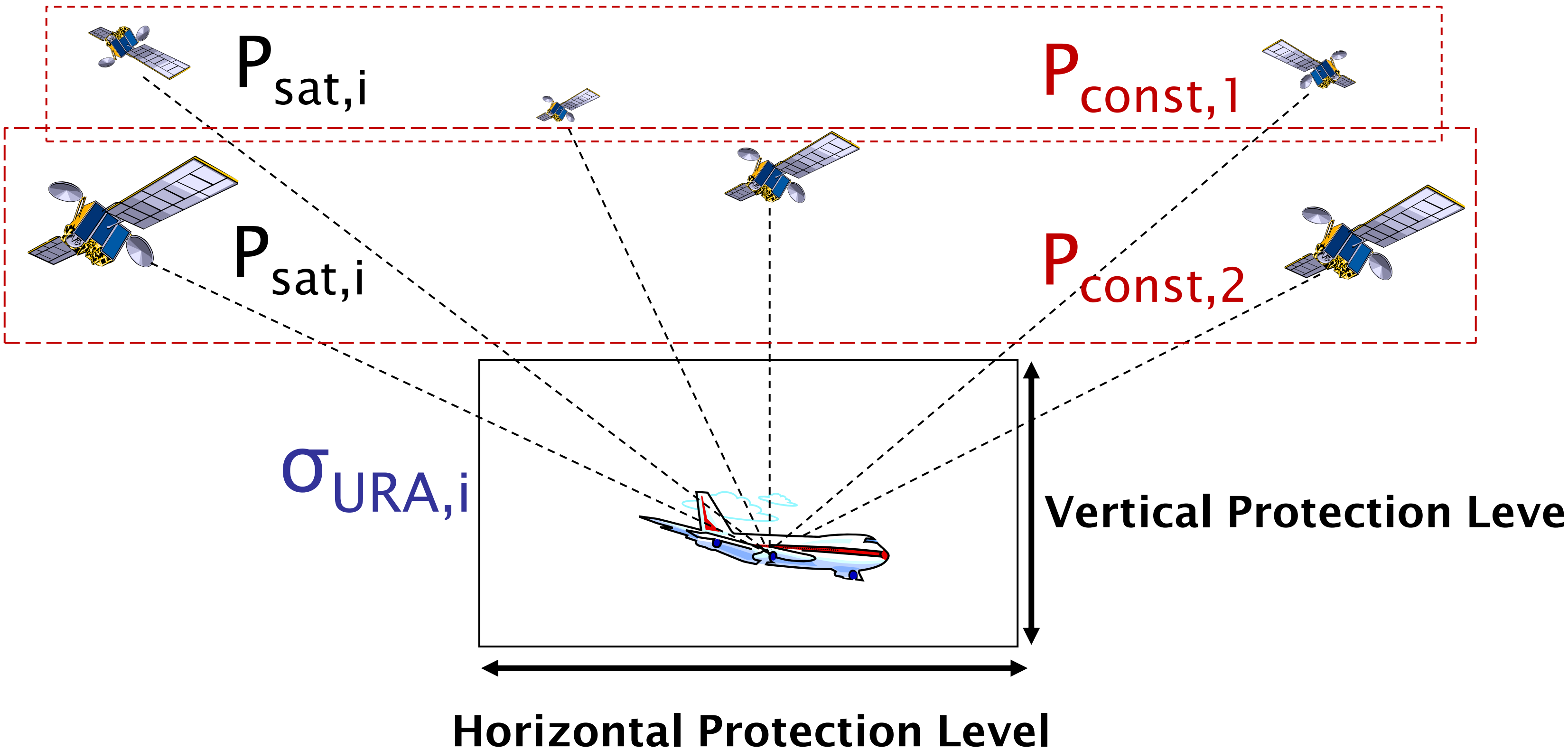
RAIM and Advanced RAIM Comparison

	RAIM	ARAIM
Operations	Down to RNP 0.1	LPV 200
Hazard category	Major	Hazardous
Signals	L1CA	L1CA/E1-L5/E5a
Threat model	Single fault only	Multiple faults
Nominal error model	Gaussian Uses bound broadcast by GPS	Gaussian + nominal/max bias validated by independent ground monitoring
Constellations	GPS	Multi-constellation

Interim Conclusion

- To be effective, ARAIM requires increased trust in core constellations and/or the supporting ground infrastructure
- Implementation architecture must provide additional trust through a bounding methodology
- Key architecture selection tradeoff decisions:
  - Threats mitigated by ground, versus threats mitigated by satellites, and/or avionics algorithm
  - Level of confidence required to validate constellation performance and how quickly a response to identified issues is needed (i.e. Time to ISM Alert (TIA) latency)?

ARAIM concept

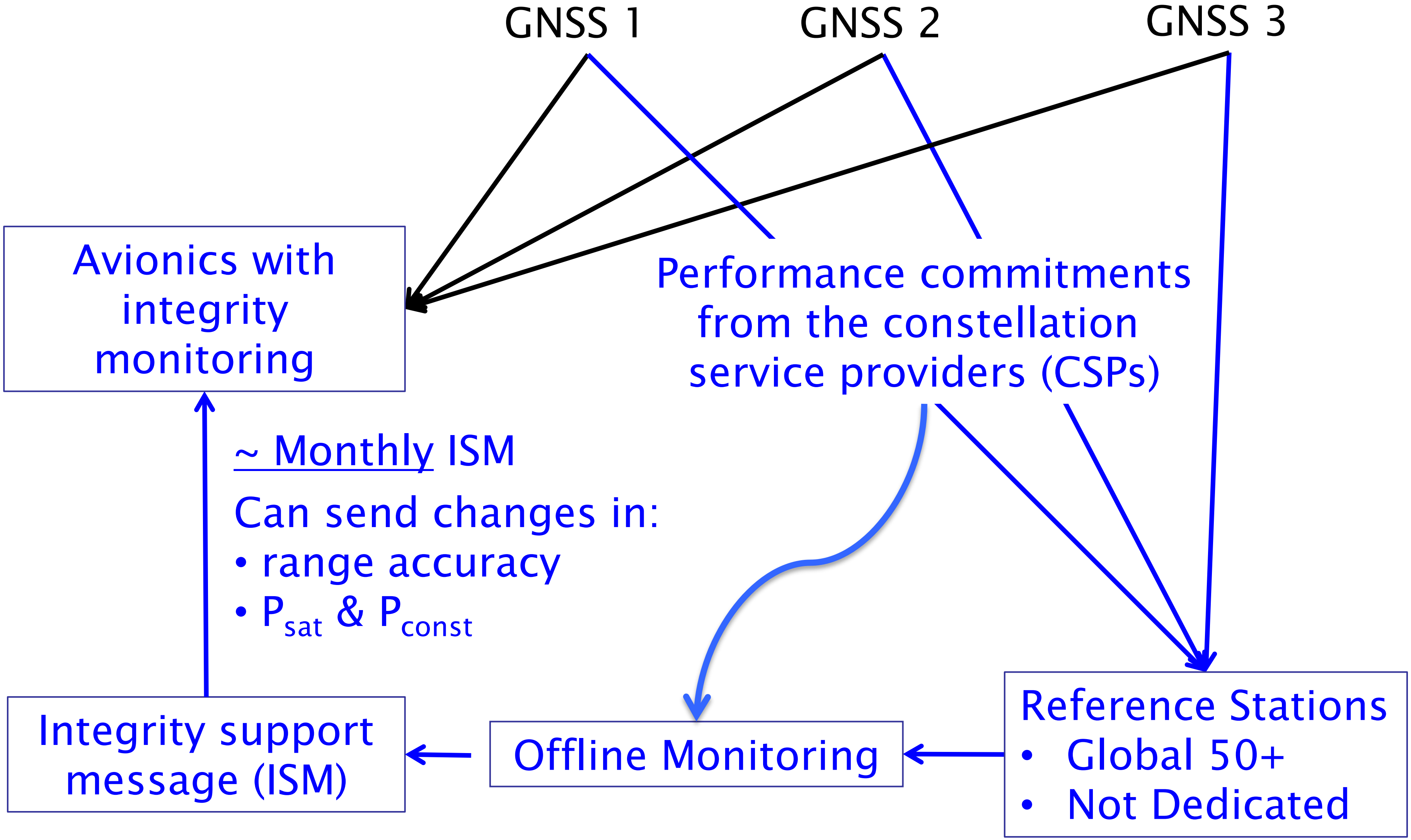


Integrity Support Message: $\sigma_{URA,i}$ $P_{sat,i}$ $P_{const,j}$

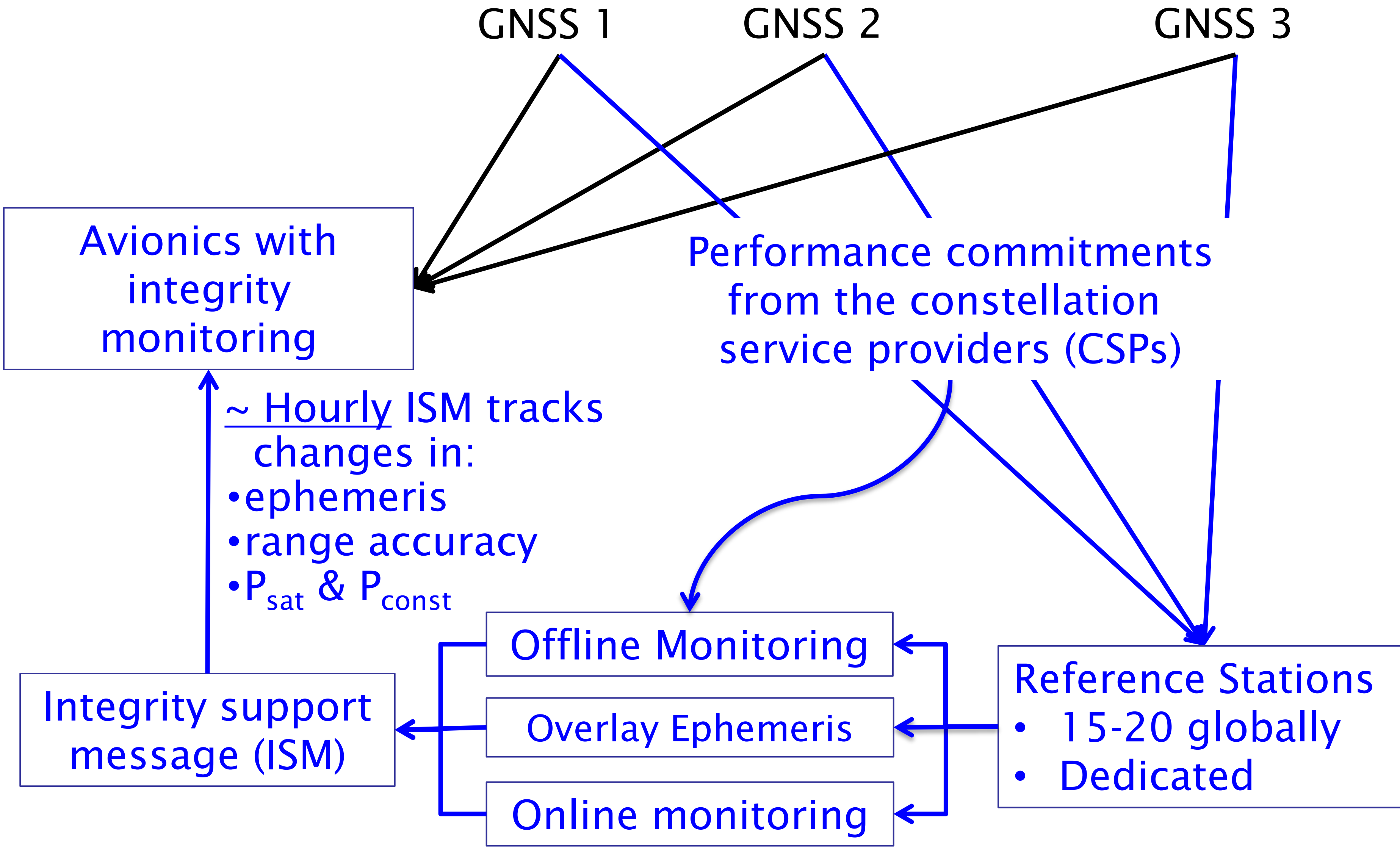
ARAIM Architecture Alternatives

- EU-U.S. working group has consolidated around two candidate architectures to provide vertical guidance
  - Offline (similar to existing RAIM)
    - Infrequently updated (~ 1 per month), quasi-static Integrity Support Message determined by post-processing data
  - Online (similar to SBAS and SoL)
    - Frequently updated (~1 per hour), dynamic Integrity Support Message with automatic updating
    - Navigation ephemeris message overlay and online monitor provide greater control over nominal errors and constellation-wide faults
- Feedback requested from aviation and other safety-of-life communities to assist in evolving both architectures and ultimately selecting one

Offline Architecture



Online Architecture



Vertical Availability Depends upon Constellation Check

OFFLINE with Airborne Constellation Cross-check: $P_{sat} = 10^{-5}$, $P_{const} = 10^{-4}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-250	LPV-250			
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-250	
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250

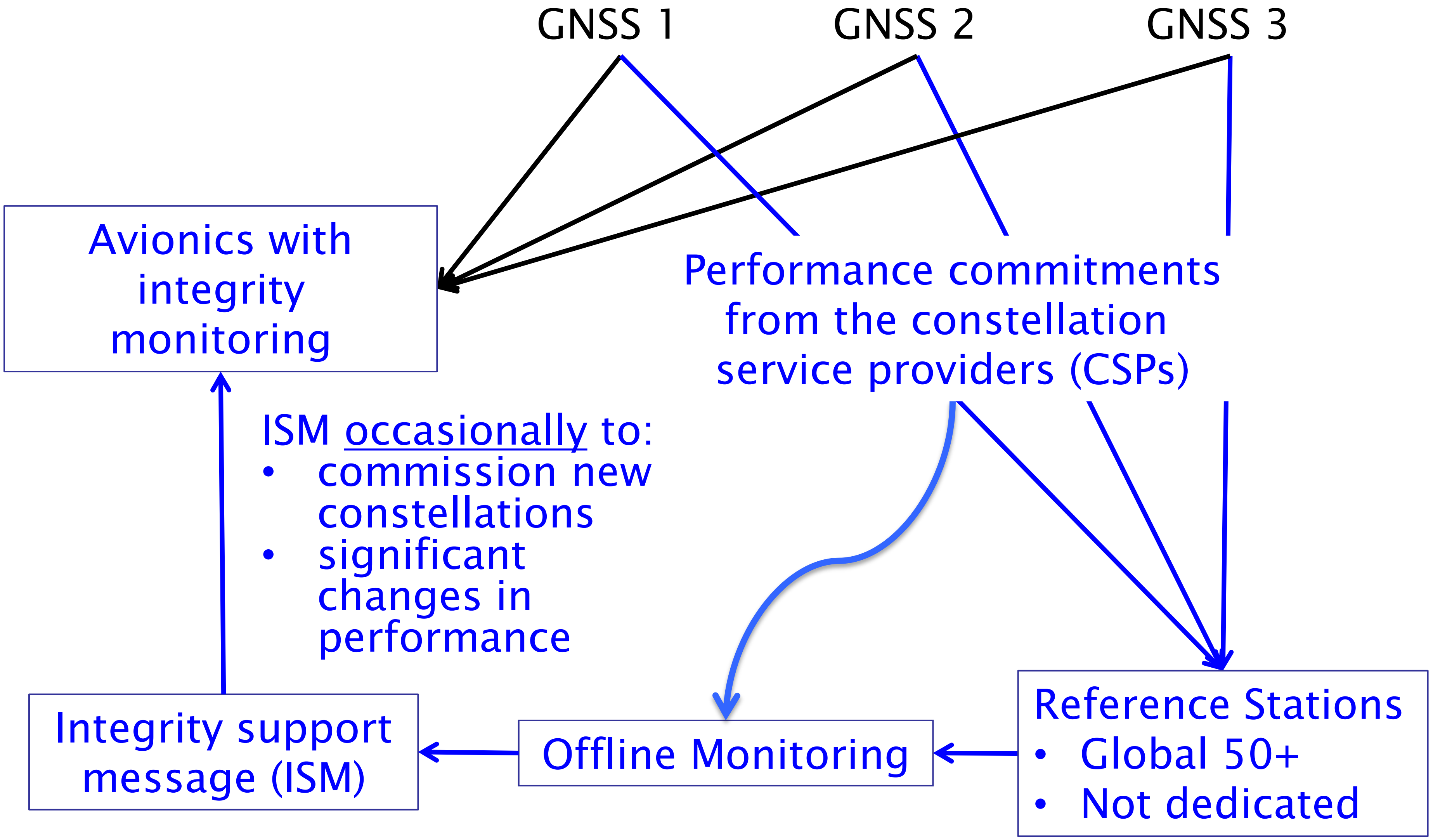
ONLINE without Airborne Constellation Cross-check: $P_{sat} = 10^{-5}$, $P_{const} = 10^{-8}$					
Constellation/URA	.5 m	.75 m	1 m	1.5 m	2 m
Depleted (GPS 23 – GAL 23)	LPV-200	LPV-200	LPV-200	LPV-250	LPV-250
Baseline (GPS 24 – GAL 24)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250
Optimistic (GPS 27 – GAL 27)	LPV-200	LPV-200	LPV-200	LPV-200	LPV-250

Color coding is based upon LPV-200 objective using the following level of service criterion: 90% coverage of 99.5% availability between -70 and 70 degrees latitude; Text indicates level of service achieved.

Horizontal ARAIM

- There is a need for an early, horizontal-only ARAIM
  - Before constellations reach fully operational capability
  - Eliminates need for pre-dispatch RAIM availability check
  - Uncomplicated, quasi-static ISM can support Horizontal-only ARAIM
    - P_{const} could be set to zero
  - Supports L1 & L5 combined, L1-only, and L5-only operations
  - Enables RNP 0.3 or better for Non-Precision Approach (NPA)

Horizontal-Only ARAIM



Horizontal Availability

L1-L5

Constellation/Pconst	GPS 10^{-4} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-8}
GPS 23 – Gal 23	RNP 0.1	RNP 0.1	HAL < 40 m
GPS 24 – Gal 24	HAL < 40 m	HAL < 40 m	HAL < 40 m
GPS 27 – Gal 27	HAL < 40 m	HAL < 40 m	HAL < 40 m

Reversionary: L5 Only

Constellation/Pconst	GPS 10^{-4} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-4}	GPS 10^{-8} Gal 10^{-8}
GPS 23 – Gal 23	RNP 0.3	RNP 0.3	RNP 0.3
GPS 24 – Gal 24	RNP 0.3	RNP 0.3	RNP 0.1
GPS 27 – Gal 27	RNP 0.3	RNP 0.3	RNP 0.1

Color coding is based upon RNP 0.1 objective using the following level of service criterion: 90% coverage of 99.5% availability between -70 and 70 degrees latitude; Text indicates level of service achieved.

Architecture Comparison

	Offline	Online
Reference network	Global (50+ stations), Non-dedicated (e.g. IGS, NASA's GDGPS)	Global (15-20 stations), Dedicated, Guaranteed Latency (2-3 RX/station)
Source of clock and ephemeris	Uses navigation messages from core constellations	Independent ephemeris overlay
ISM generation	Offline analysis and validation of post processed data	Online monitoring (automatic)
ISM latency	Days to Weeks	Hours
Broadcast channel options	Aeronautical Database, ATC Datalink, VDB, core constellation spare bits	ATC Datalink, VDB, Alternate PNT, GEO, core constellation spare bits

Questions (slide 1 of 3)

1) Single global ISM vs. multiple ISMs?

Discussion points:

- May not be possible to agree on a common global ISM
  - Would need to Link specific ISMs to specific airspaces

2) Need for Horizontal-only early services
  - No guarantee of service before constellations full ops capability
  - Constellations may not be fully populated
  - Accuracy may be less than planned for full operational capability
  - Reliability may be limited
  - Service commitments may not be available

Questions (slide 2 of 3)

3) Scope and cost of ground monitoring infrastructure

- One shared by all or one per each air navigation service provider?

4) Acceptable means for ISM dissemination

- What is the most practical means to get ISM data to a receiver?
- Is the use of an updatable database acceptable?

5) Which data links are acceptable?

- Which are preferred?

Questions (slide 3 of 3)

6) Is global LPV-200 service a target that will motivate development and provision of ISM and ARAIM incorporation in receivers/aircraft?
   - Is global RNP 0.1 to 0.3 without the need for a pre-departure RAIM availability check a motivator in avionics selection?

7) Which features of each architecture are most attractive?
   - Which features are most problematic?

8) What are we missing?

Status

- Milestone IIB Architecture Report planned for release in late 2014
- Report will be posted at both:
  - http://www.gps.gov/policy/cooperation/ and
  - http://ec.europa.eu/enterprise/newsroom
- Mechanisms will be provided for feedback from:
  - International Civil Aviation Organization's Navigation System Panel
  - RTCA and Eurocae aviation standards bodies
  - International Committee on GNSS
  - Others as appropriate
- Comments received will be considered in production of the Final ARAIM report (2015)

Conclusions

- ARAIM will have a quasi-static ISM to support horizontal navigation using multiple constellations
- Proposing two potential architectures to support vertical navigation:
  - Offline Architecture: provides a quasi-static ISM that is determined from post-processed data and rarely updated (~1 each month)
  - Online Architecture: provides a dynamic ISM that is automatically generated (~1 each hour)
- Primary discriminators are LPV-200 availability and level of effort required to develop and maintain the architectures
  - Offline has greater dependence on the performance of the constellations; the ISM may have limited availability depending upon the performance of the constellations
  - Online may provide higher availability using smaller ISM parameters, but will require greater effort to set up and maintain the architecture
- Neither architecture is advocated over the other
  - We are seeking feedback from aviation and other safety-of-life users on the acceptability of either architecture

Summary

- ARAIM is a promising solution for the provision of integrity in the future
- It can exploit multiple constellations and support diverse technical/institutional set-ups in different regions
- Service Commitments from Service providers will be an important pillar for ARAIM (ref. discussions in ICG WG A)
- Consistent monitoring solutions for ARAIM can also be addressed in the context of ICG
- Final proposed ARAIM concept (when available) needs international standardization in order to accommodate all core constellations and provision of ISM
- Aviation community consultation will be actively pursued in traditional fora such as ICAO and RTCA/EUROCAE
- EU and U.S. expect to provide additional documentation in the near term

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Eric Chatre, European Commission

Eric.Chatre@ec.europa.eu

Ken Alexander, Federal Aviation Administration

Ken.Alexander@faa.gov

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This briefing summarizes the current assumptions and progress of Working Group-C. The Working Group will continue to investigate ARAIM assumptions, algorithms, and candidate architecture implementations in order to mature the concept.