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

Ken Alexander, Federal Aviation Administration
Eric Chatre, DG Enterprise and Industry

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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.

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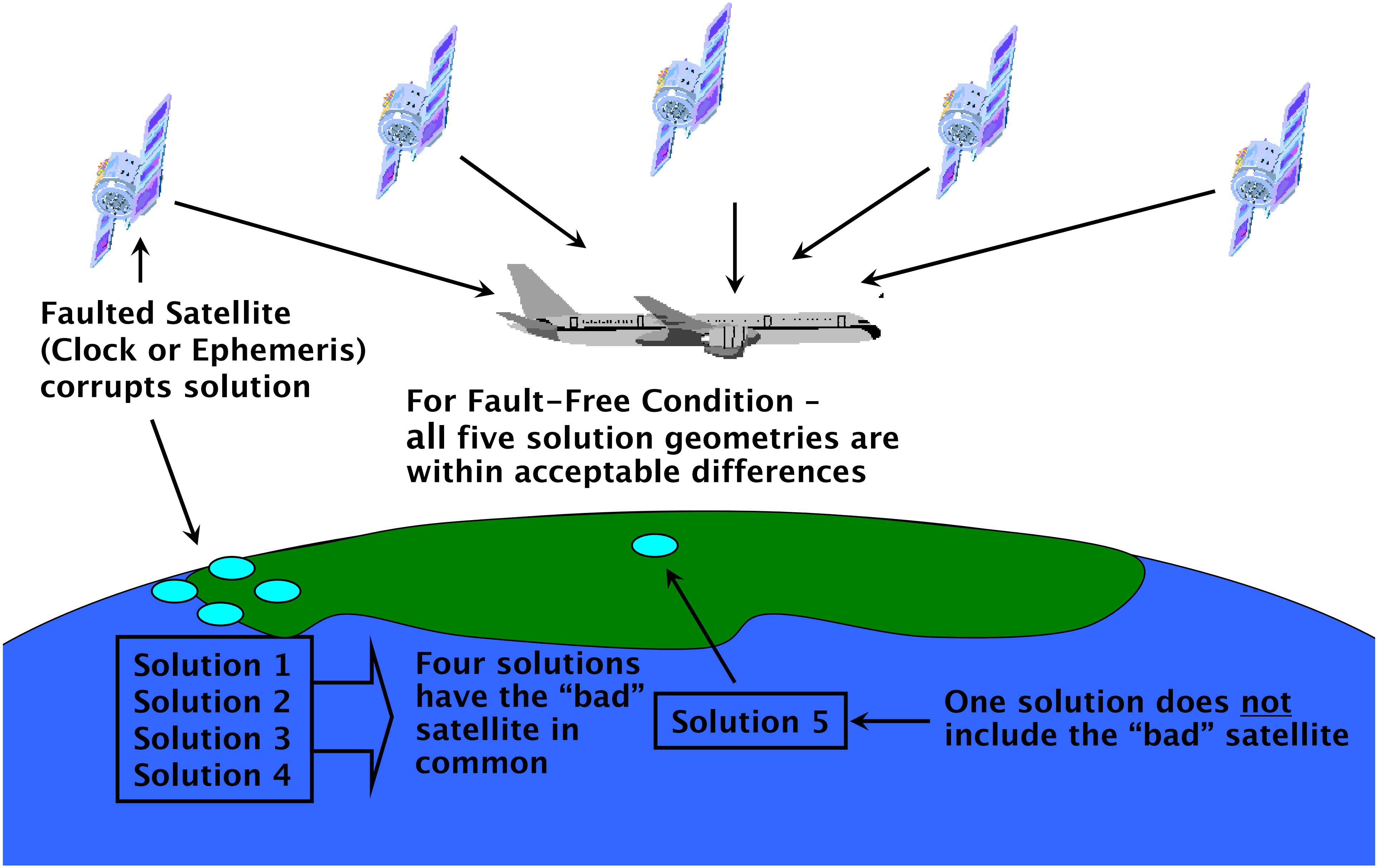
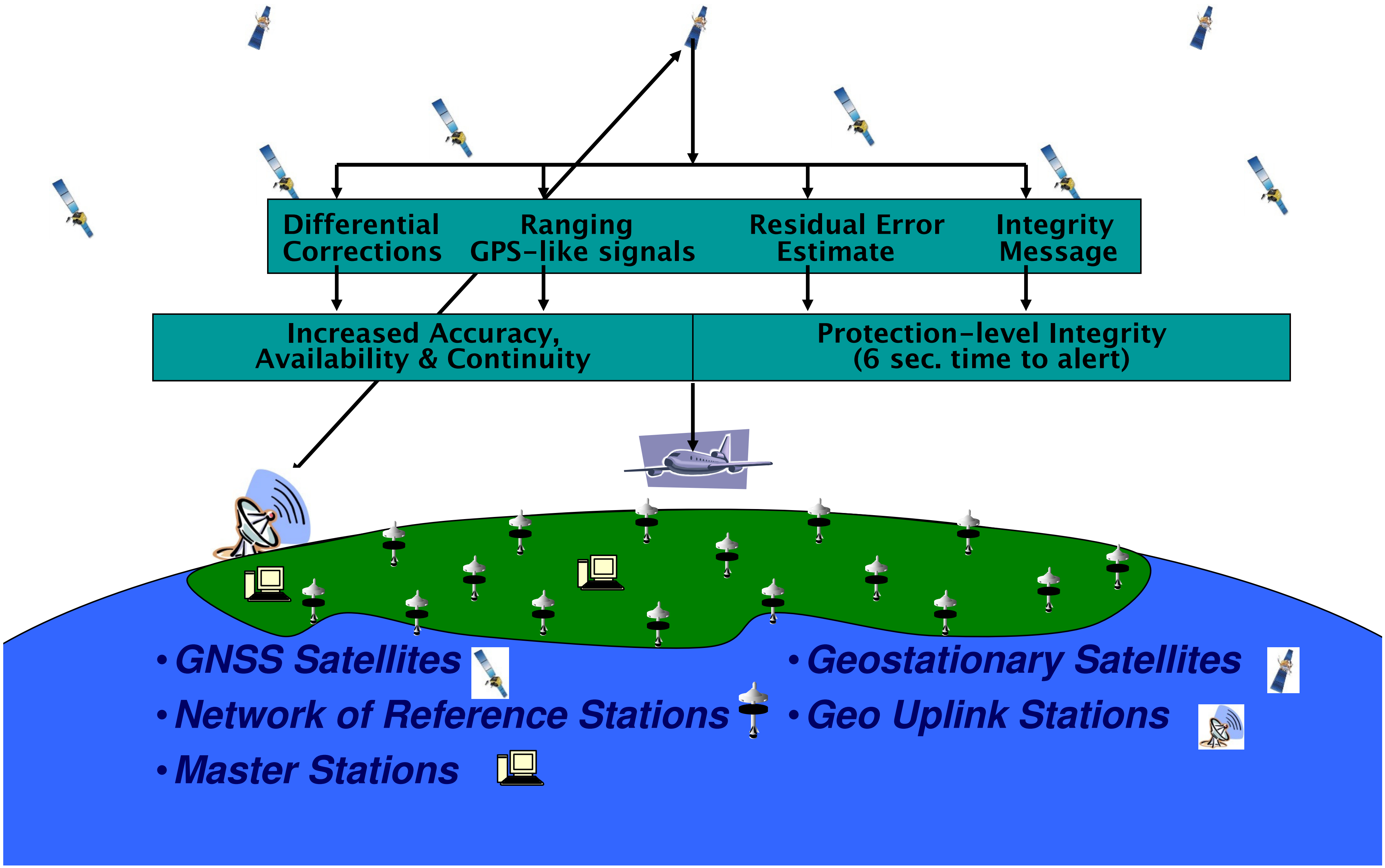
EU-US GNSS Cooperation in WG-C

- On 29 July 2010, the Government of the United States, the European Union (EU) and its Member States announced the conclusion of an initial phase of consultations affirming user interoperability and enhanced performance of combined GPS and Galileo receivers performance under the auspices of their
  - 2004 *Agreement on the Promotion, Provision and Use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications*
- U.S./EU GPS-Galileo Agreement established Working Group C "to promote cooperation on design and development of next generation of civil satellite-based navigation and timing systems"
- A key element of the agreed work programme is investigation of different candidate concepts for provision of integrity services in the future

RAIM Architecture



SBAS Architecture



Advanced Receiver Autonomous Integrity Monitor (ARAIM) Study

- ARAIM Study Objectives:
  - Define a reference multi-constellation ARAIM concept allowing vertical guidance (LPV, LPV-200) and worldwide coverage
  - Harmonize understanding of concept and provide a basis for standardization
- Bilateral Group established July 2010
- Membership includes: FAA, ESA, Stanford University, European Commission, IIT, MITRE, DLR, University FAF Munich, EUROCONTROL, CNES
- Members involved in development or certification of RAIM, WAAS, EGNOS, GBAS and Galileo

ARAIM Implementations

- ARAIM provides a means of providing vertical, as well as horizontal, aircraft guidance
- Avionics compares various ranging measurements to different satellites to ensure they are consistent
- To meet aviation integrity requirements, the satellites must perform within a certain set of expectations
- Many individual aviation authorities may likely independently monitor satellite performance and 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 in some combination
- Each ARAIM architecture will require an allocation strategy and then each segment can be assessed relative to its goal

ARAIM Implementations (continued)

- Architectures that put little trust in satellites, or GNSS ground segment, might assume a very high probability of signal-in-space failure and might provide a lower level of integrity service unless the aircraft has exceedingly good geometry to detect all possible faults
- Other architectures that establish either more trust in GNSS ground and space segment performance or provide an ARAIM supporting ground infrastructure can operate with comparatively weaker geometries
- Different service providers may make different architectural choices
  - Those invested in SBAS may choose to re-use their monitoring networks and delivery channels
  - Those that have not invested in monitoring networks may opt to put more burden on the aircraft and rely upon other States' or international monitoring networks
  - Ideally, ARAIM can allows such differences to co-exist without incurring significant complexity in the avionics

KEY ARAIM ARCHITECTURAL PROPERTIES

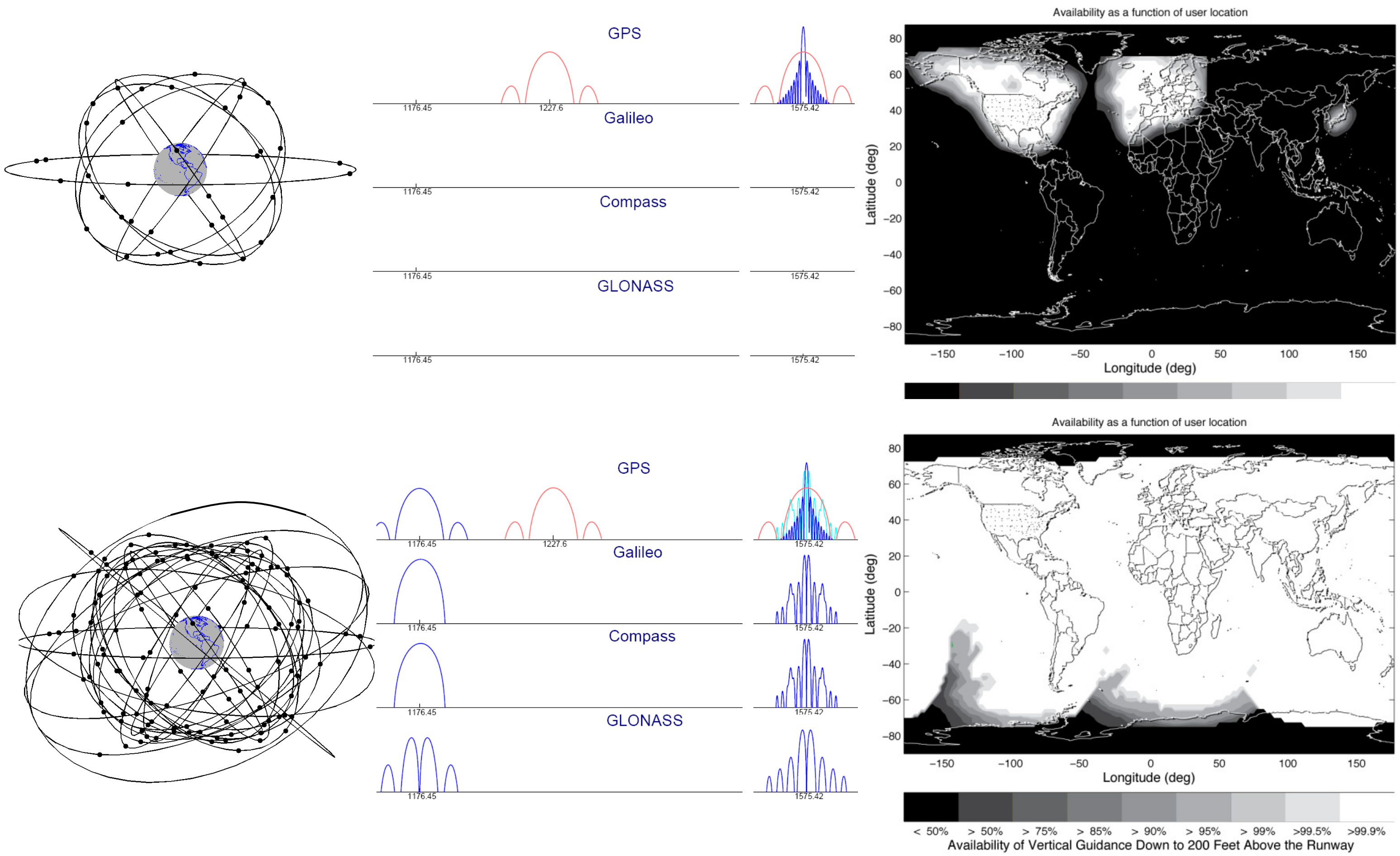
- Key architectural properties are:
  - Bounding methodology (ranging quality, GNSS failures)
  - Communication and computation latency
  - Broadcast methodology
  - Integrity Support Message (ISM) contents
  - Handling of constellation faults
  - Reference network
- Properties are strongly interconnected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

Evolution of Global Navigation Satellite Systems

constellations | signals | vertical guidance

2011

2025



RAIM and Advanced RAIM Comparison

	RAIM	ARAIM
Operations	Down to RNP 0.1	LPV200
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

Advanced RAIM User Algorithm – Step by Step

- Integrity Support Message (ISM) parameters describe both the nominal error behavior and the probability of fault of one (or more) satellites
- Nominal error is characterized by two sets of standard deviation and maximum bias, the first one for integrity purposes and the second less conservative one, for accuracy and continuity evaluation purposes
- Nominal error model computation as a function of the Integrity Support Message content
- The aircraft receiver determines which faults must be monitored based on contents of the ISM, including the subset solutions of satellites that must be computed and compared against the all-in-view solution

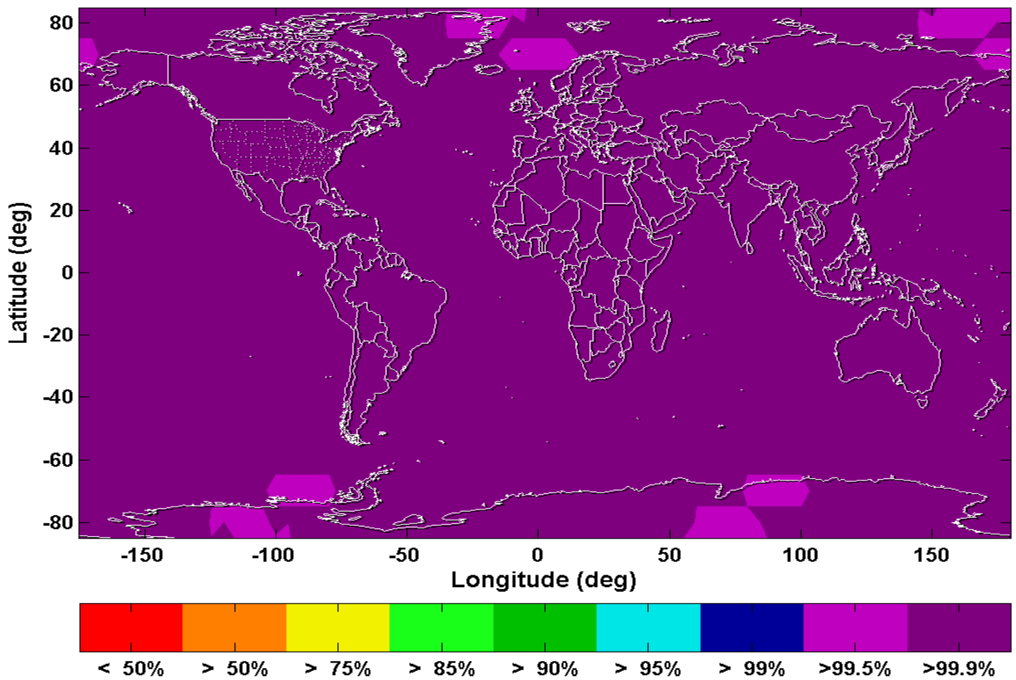
Advanced RAIM User Algorithm – Step by Step (continued)

- Based on test results from solution separation tests, fault exclusion is attempted when one of these test statistics has exceeded its threshold
- If the all-in-view set is found to be inconsistent, the algorithm may have to exclude a subset of satellites and we determine the best candidate for exclusion
- Protection Level calculation; if a large number of faults needs to be monitored, correspondingly a large number of subset solutions must be computed

Advanced RAIM User Algorithm – Step by Step (continued)

- An exclusion test confirms that the proposed excluded satellite (or group of satellites) appears to be faulty; If the test doesn't pass, it means that the subset that is being tested is itself a suspect. Therefore its prior probability needs to be increased
- Finally, the study identified possible baseline algorithm improvements: false alert risk allocation among modes, Protection Level calculation, threat model modifications, position solution calculation, ground validated long-term ephemeris for EOP faults and test simplification means
- **For technical details and formula to establish test statistic, protection level equation, exclusion function to identify faulty satellites, exclusion function (with example) and rank one update formulas for subset computation, see slides & supplemental technical charts posted at:**
  http://www.gps.gov/multimedia/presentations/2012/11/ICG/

Availability Simulations: 99.5% LPV-200 Availability



GPS 24 + Galileo 27

- 10 sidereal days
- 5x5 degrees user grid
- 300 sec. time steps
- URA = .75 m
- SISA = .96 m

	$P_{sat}=10^{-5}$	$P_{sat}=10^{-4}$	$P_{sat}=10^{-3}$
$P_{const}=10^{-6}$	100%	100%	100%
$P_{const}=10^{-5}$	95.84%	92.01%	89.32%
$P_{const}=10^{-4}$	64.96%	54.60%	51.17%

Next Steps

- ARAIM architecture consolidation
  - Continue ARAIM definition work and coordinate with WGC-ARAIM TSG
  - Perform GNSS observation and real measurement campaigns
- Avionics standardization
  - Service Performance Specifications are an important element
  - What are the high level architectures that we want to prepare for standardization?
    - Current avionics:
      - GPS L1 & GPS L1/GLONASS LIOC (Russian domestic)
    - Currently planned:
      - GPS L1/L5 + Galileo E1/E5a + RAIM (+Baro)
      - GPS L1/L5 + Galileo E1/E5a + SBAS
    - Additional:
      - GPS L1/L5 + Galileo E1/E5a + ARAIM ?
      - ARAIM in combination with other constellations ?

Summary (1)

- An efficient Advanced RAIM airborne algorithm:
  - Supports Multi-constellation use
  - Uses multiple fault threat models
  - Like conventional RAIM Is based on solution separation
- The core constellations, ground monitoring network, ISM and described fault detection and exclusion algorithm:
  - Can meet LPV-200 integrity requirements
  - Not computationally intensive (if GNSS constellation plus potential support infrastructure provide sufficient performance)
- To be effective, ARAIM requires significantly increased trust in core constellations and/or supporting ground infrastructure
- Implementation architecture and agreements 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 is a response to problems needed (i.e. Time to ISM Alert (TIA) latency)

Summary (2)

- 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
- Additional results are expected in 2013 in the context of EU-U.S. cooperation and will be presented to UN-ICG
- Aviation community consultation will also 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

Thank you

Ken Alexander, Federal Aviation Administration

Ken.Alexander@faa.gov

Eric Chatre, European Commission

Eric.Chatre@ec.europa.eu

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