The Future of Satellite Navigation for Aviation

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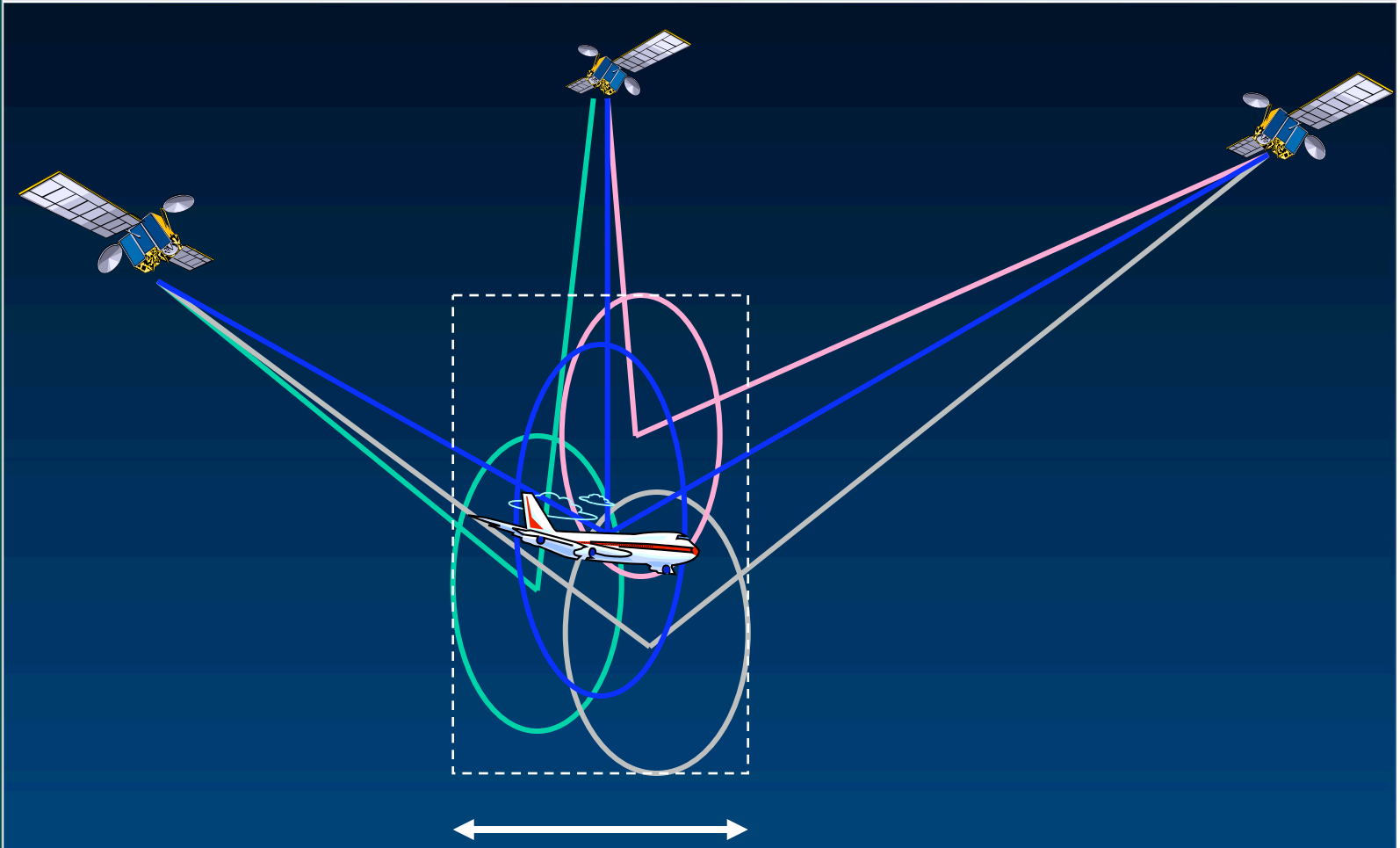
Current Satellite Navigation Use by Aviation

- Receiver Autonomous Integrity Monitoring (RAIM)
- Ground Based Augmentation Systems (GBAS)
  - *LAAS*
- Space Based Augmentation Systems (SBAS)
  - *WAAS*
  - *EGNOS*
  - *MSAS*

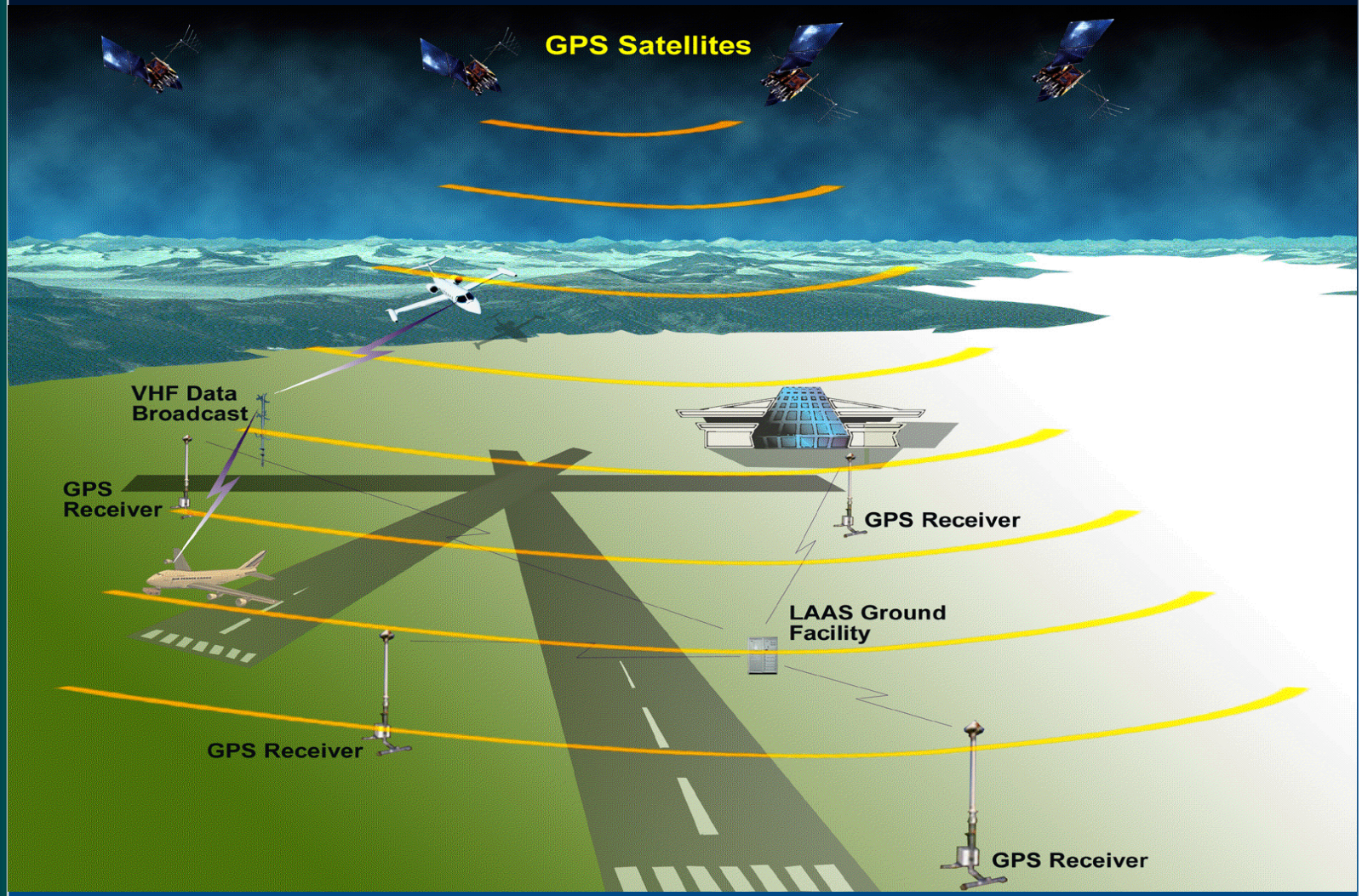
RAIM Protection



Horizontal Error Bound

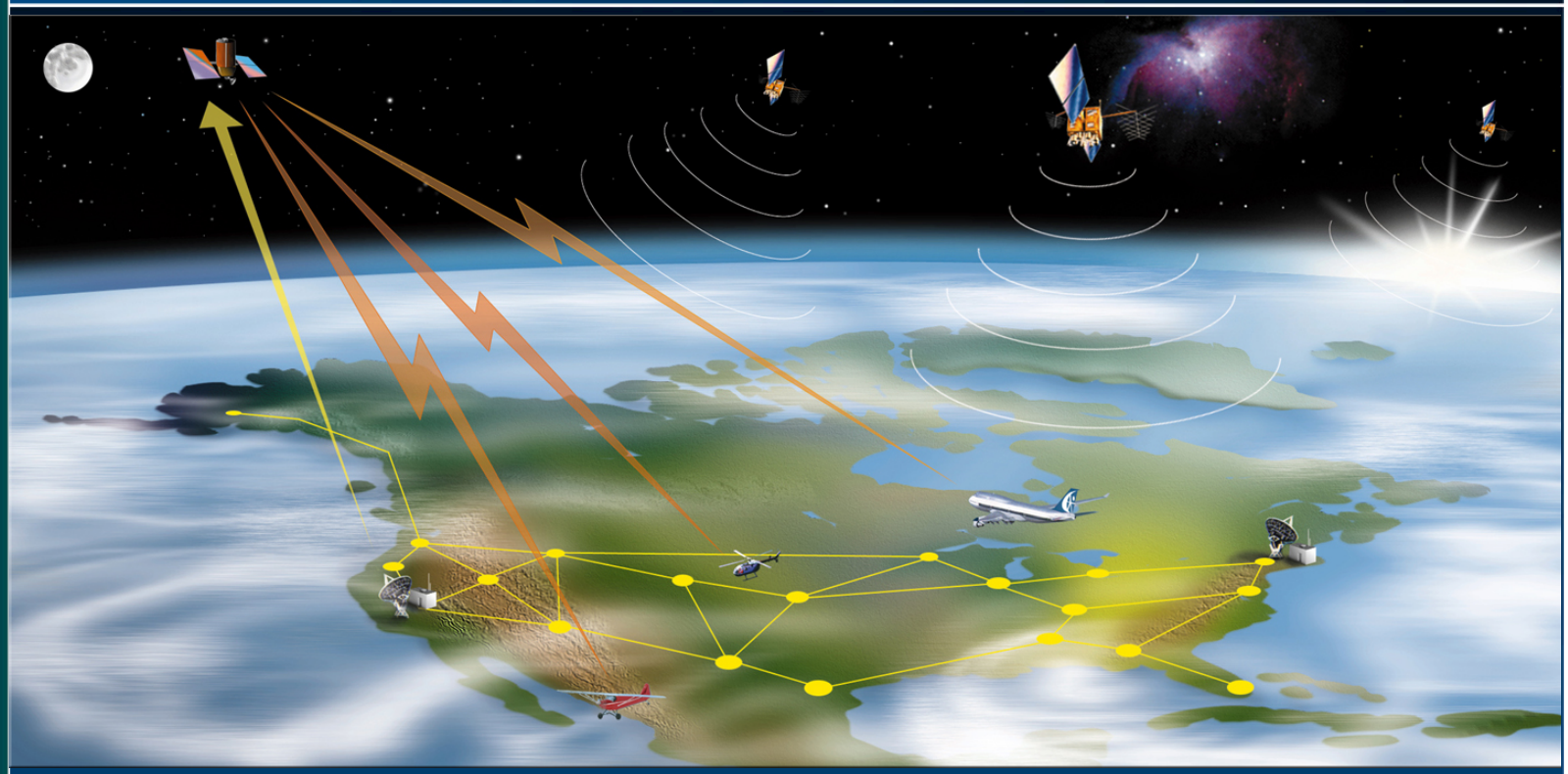
Courtesy:
Juan Blanch

GBAS/LAAS Concept



Courtesy: FAA

WAAS Concept



Courtesy: FAA

- ***Network of Reference Stations***
- ***Master Stations***
- ***Geostationary Satellites***
- ***Geo Uplink Stations***

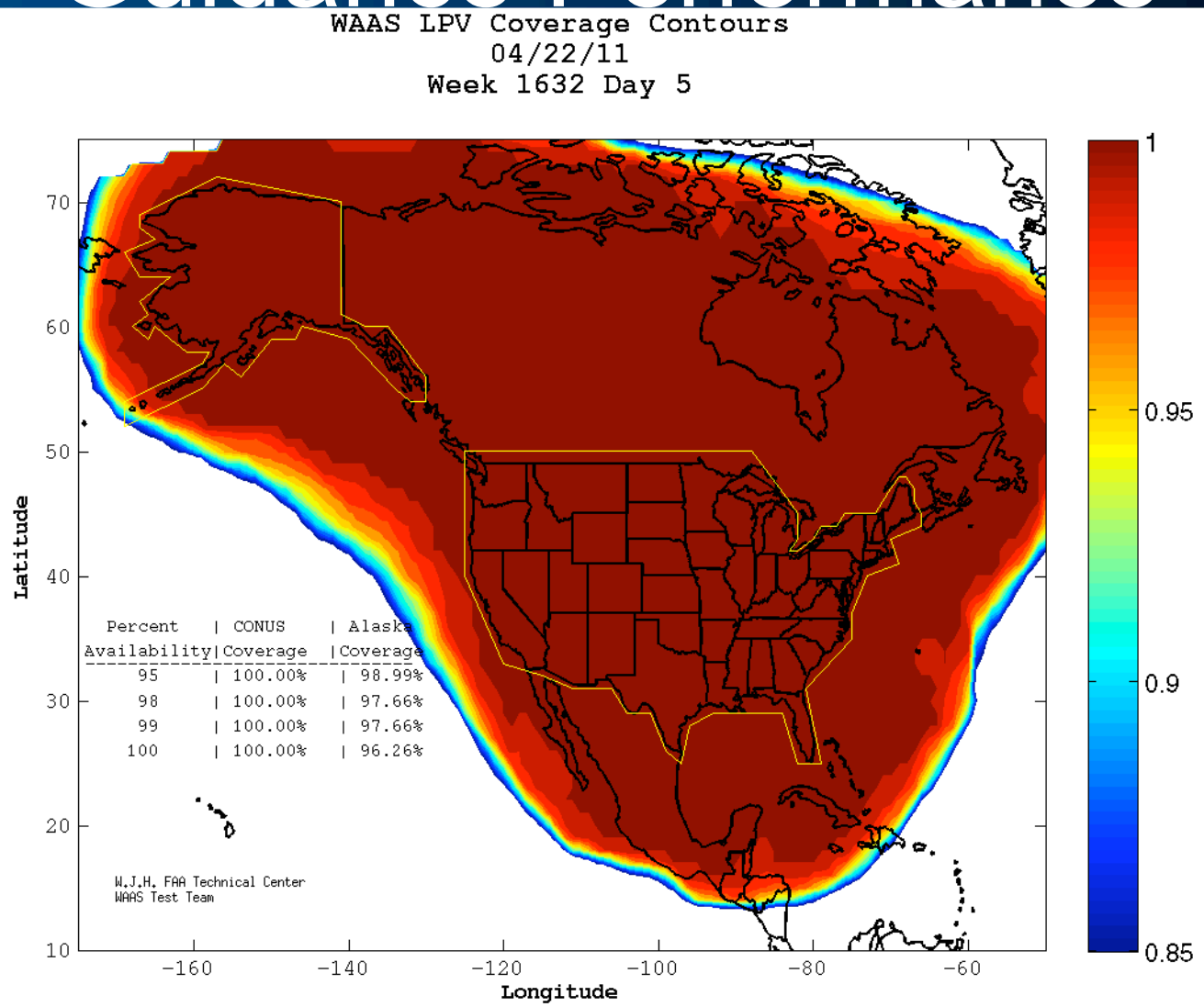
Aviation Pace of Adoption

- Avionics are designed into airplane
- Aircraft stay in service for 20+ years
  - *Rarely retrofitted after production*
- Certified avionics are slow to develop
  - *Must work with other components*
- GPS functionality still not in all commercial aircraft
  - *In late 2009 Boeing estimated that the majority of existing fleet had no GNSS*

Outline

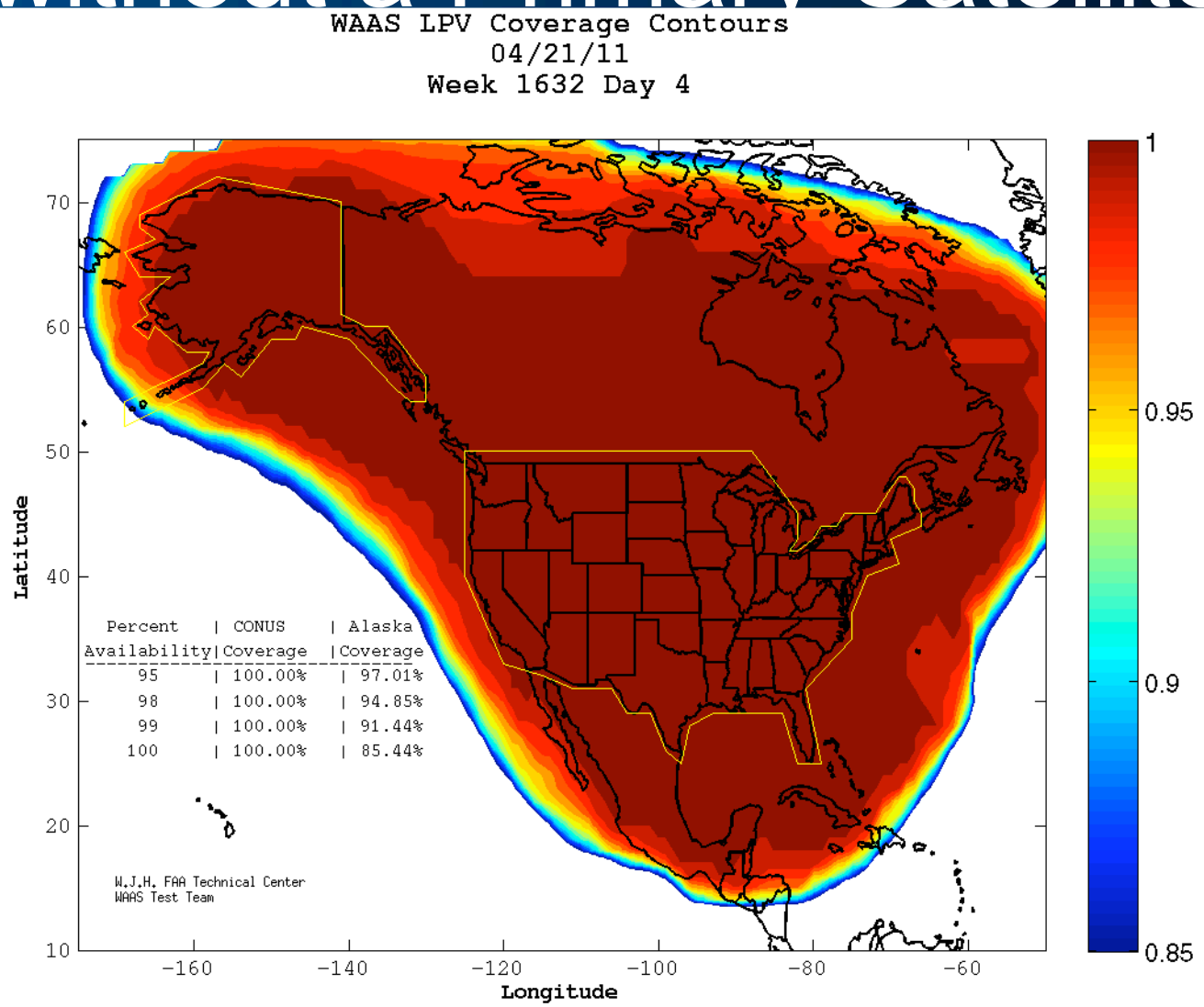
- Current challenges
  - *Geometry weakness*
  - *Ionospheric delay*
  - *Radio Frequency Interference (RFI)*
  - *Ionospheric scintillation*
- Opportunities
  - *Multiple constellations*
  - *Multiple frequencies*
  - *Augmentations/ARAIM*
  - *Integration with other sensors*

Nominal WAAS Vertical Guidance Performance



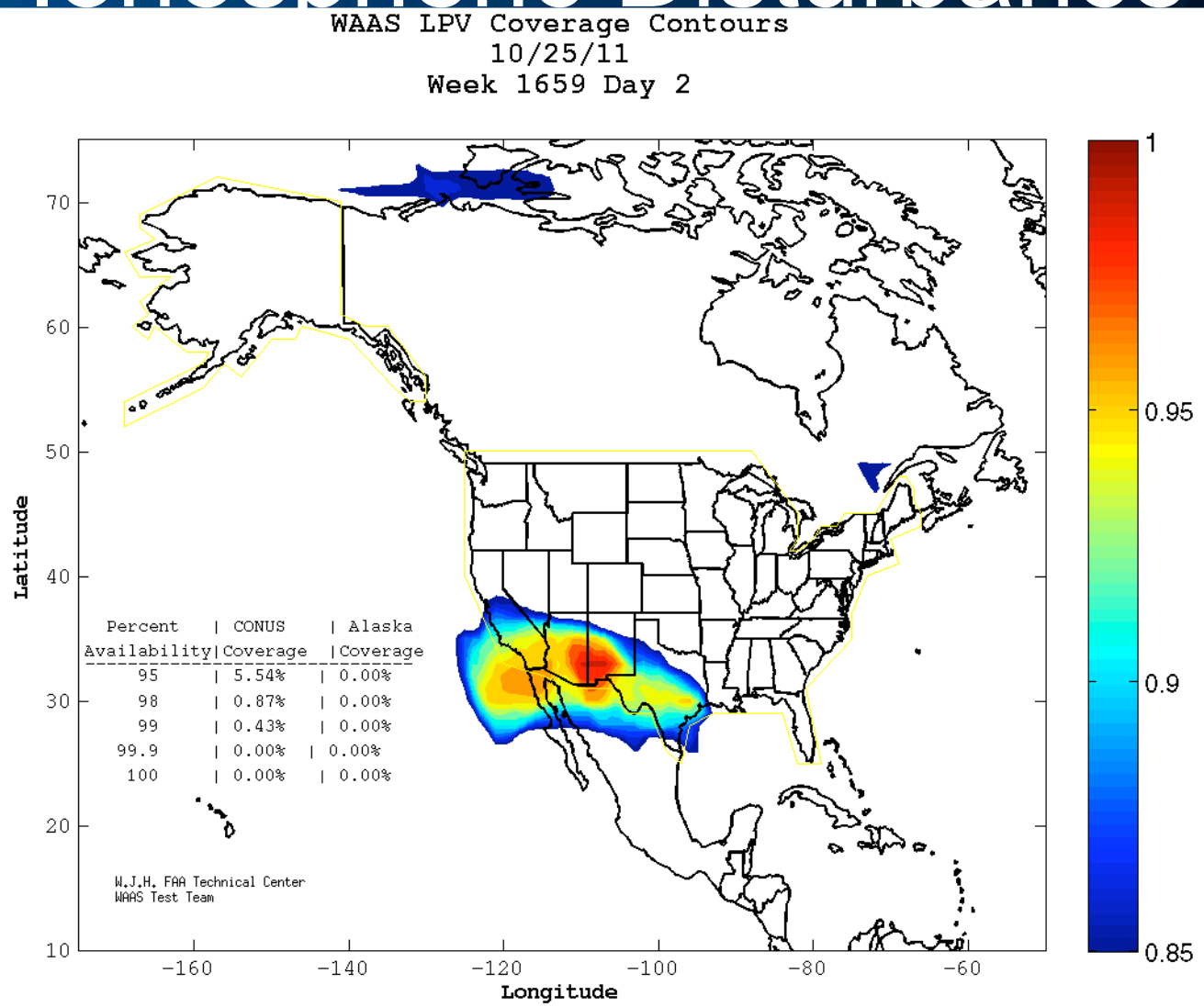
Courtesy: FAA

WAAS Vertical Guidance without a Primary Satellite



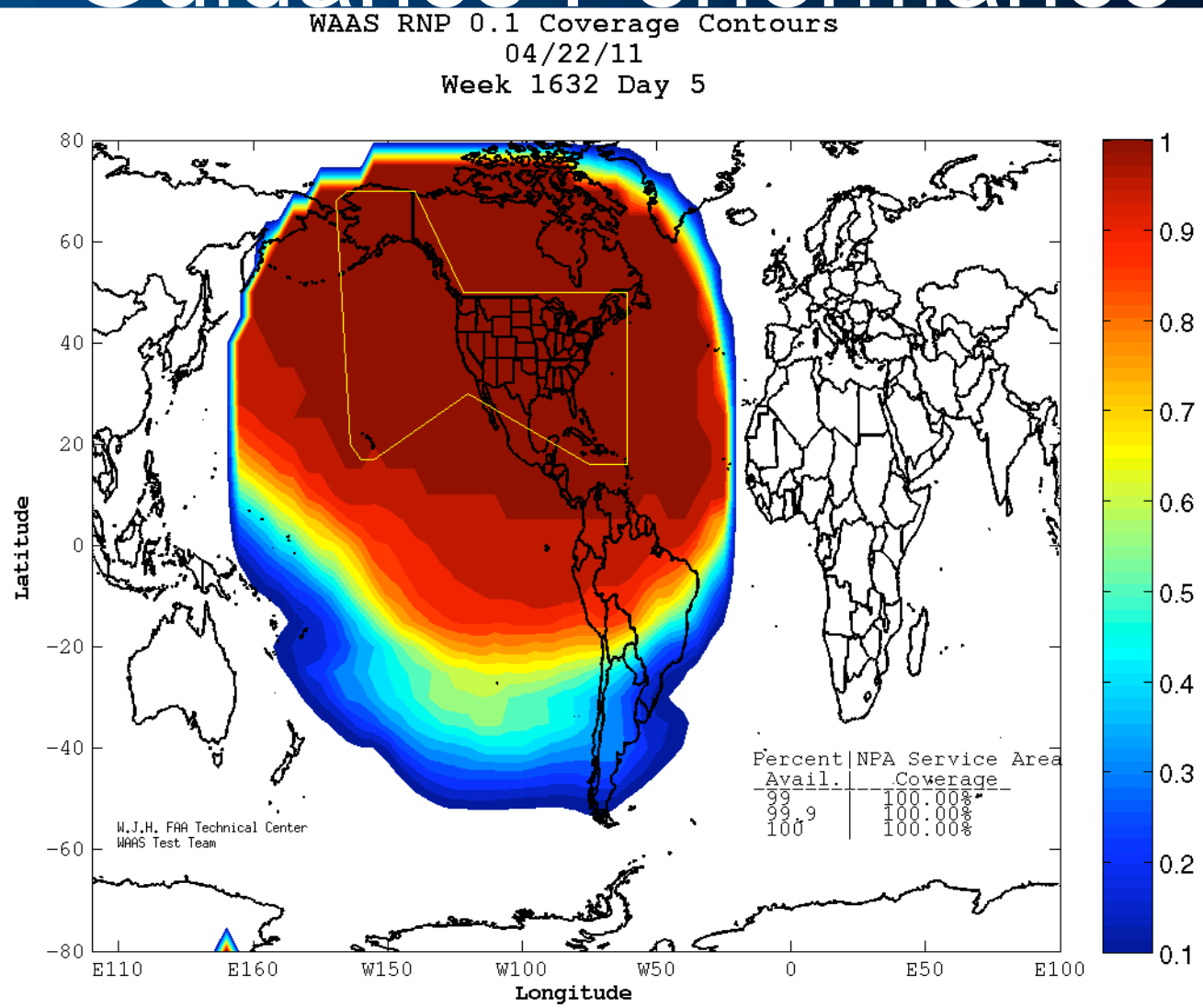
Courtesy: FAA

Vertical Guidance with Major Ionospheric Disturbance



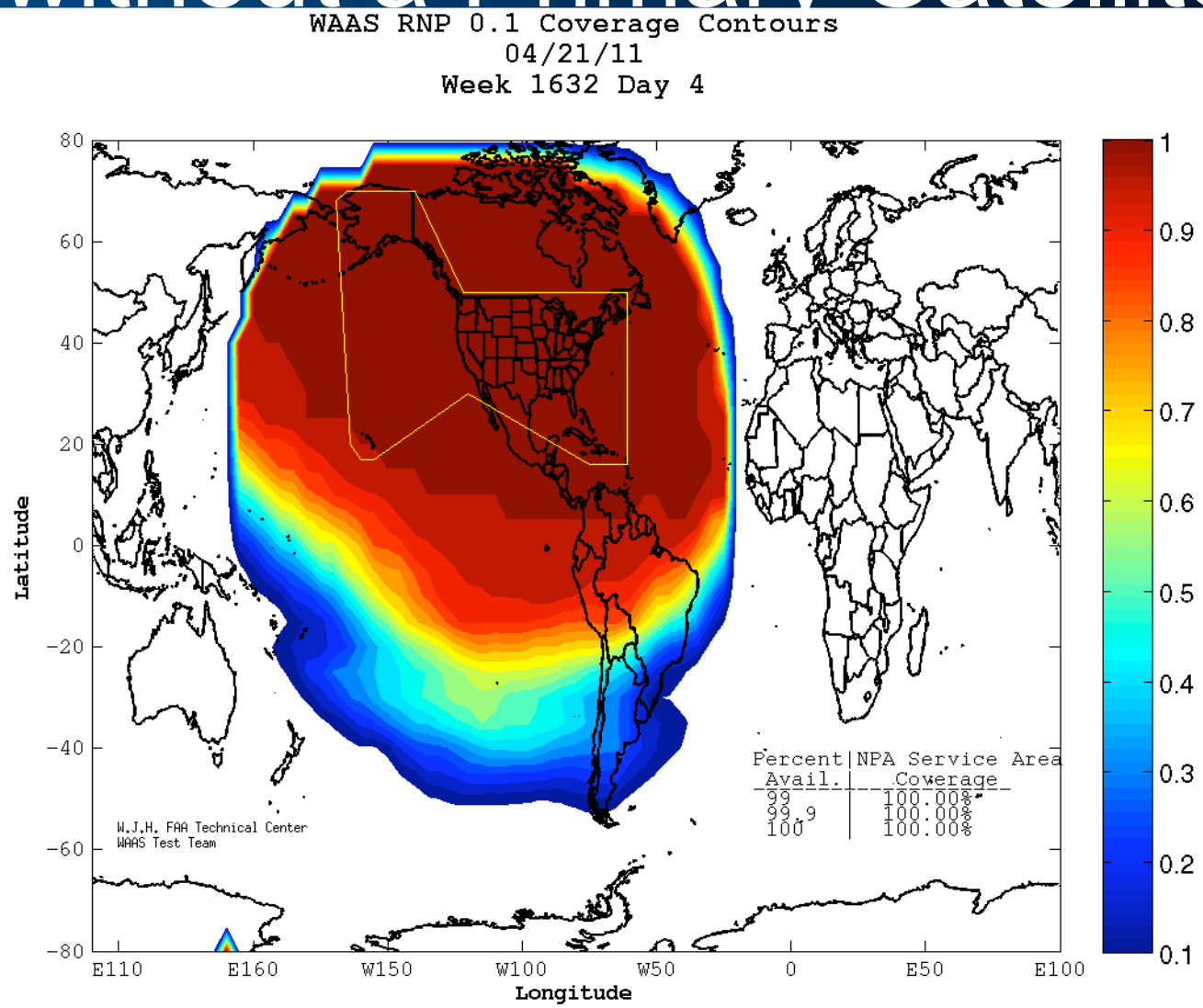
Courtesy: FAA

Nominal WAAS Horizontal Guidance Performance



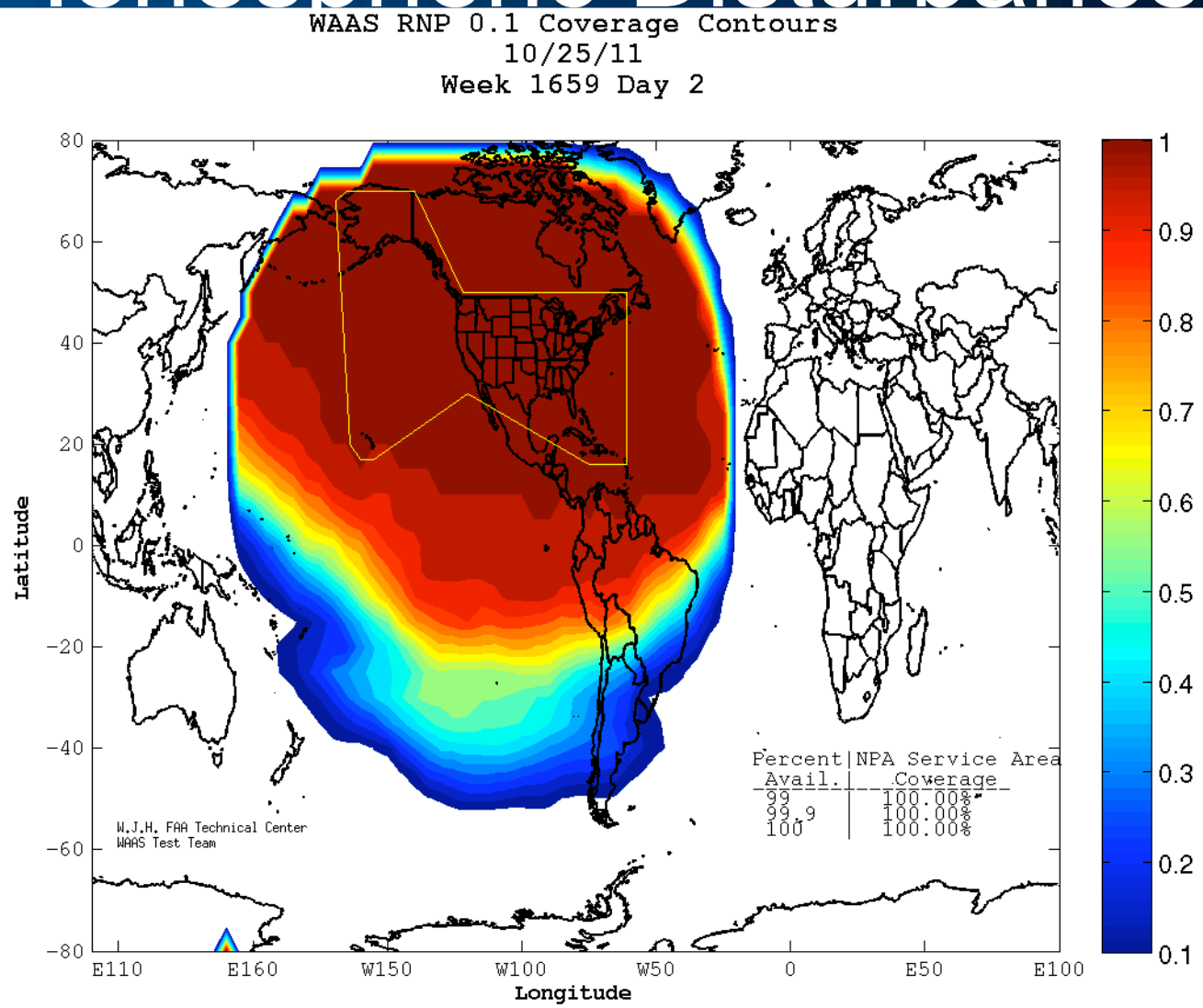
Courtesy: FAA

WAAS Horizontal Guidance without a Primary Satellite



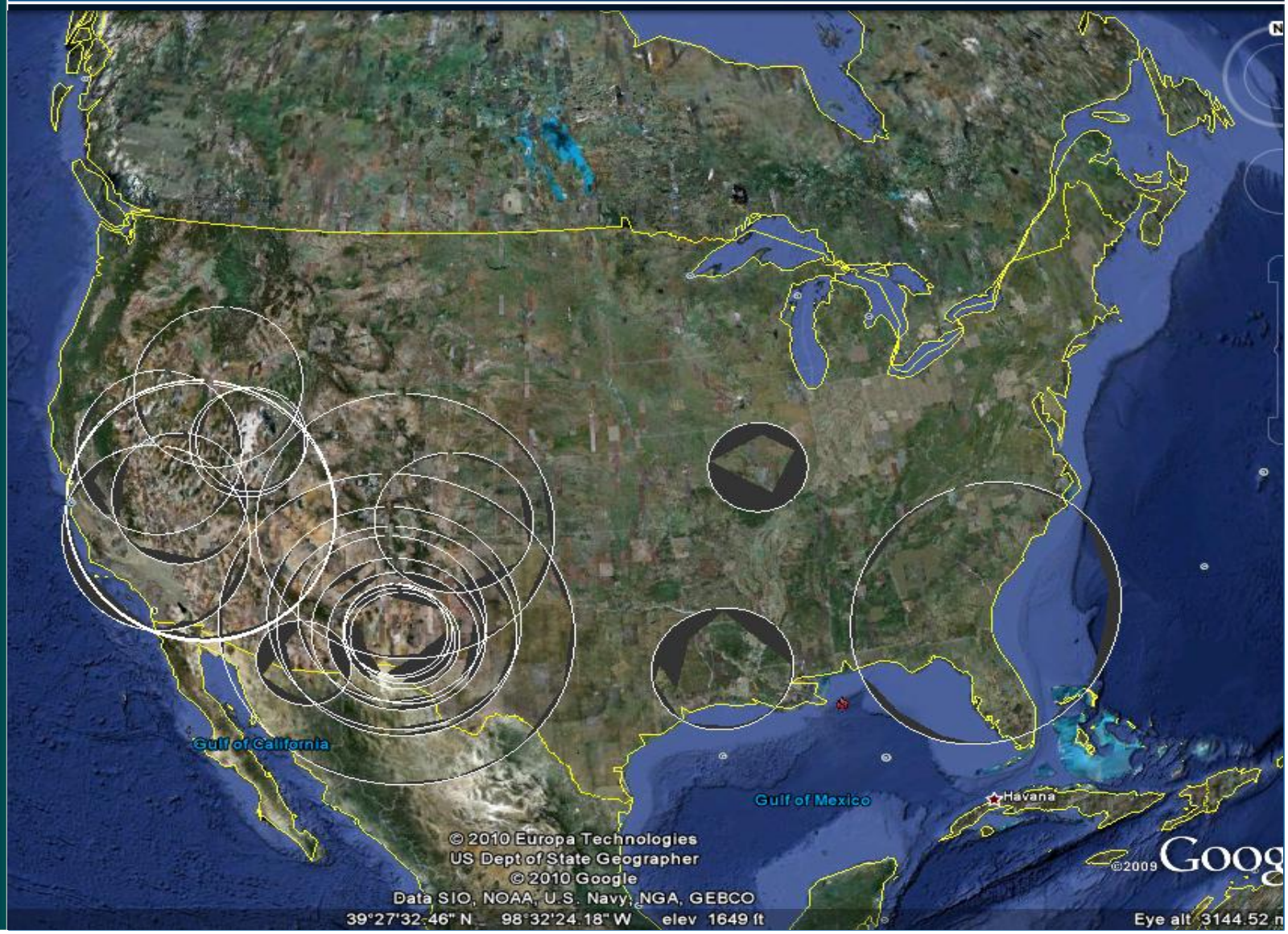
Courtesy: FAA

Horizontal Guidance in Major Ionospheric Disturbance



Courtesy: FAA

Announced GPS Testing March – Dec 2009



Personal Privacy Devices

much privacy do we expect? – The Washington Post 11/13/11 12:26 PM

The Washington Post

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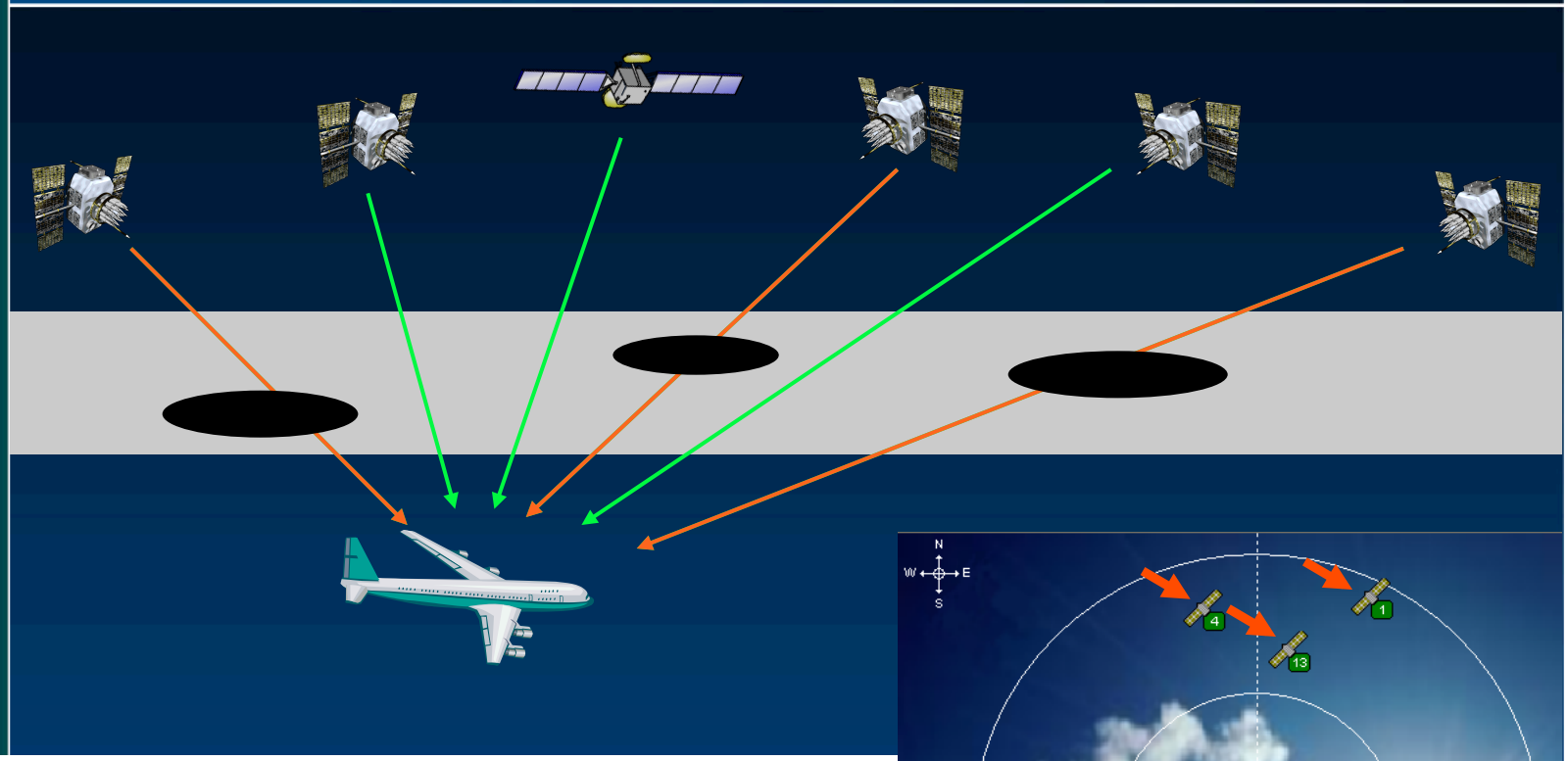
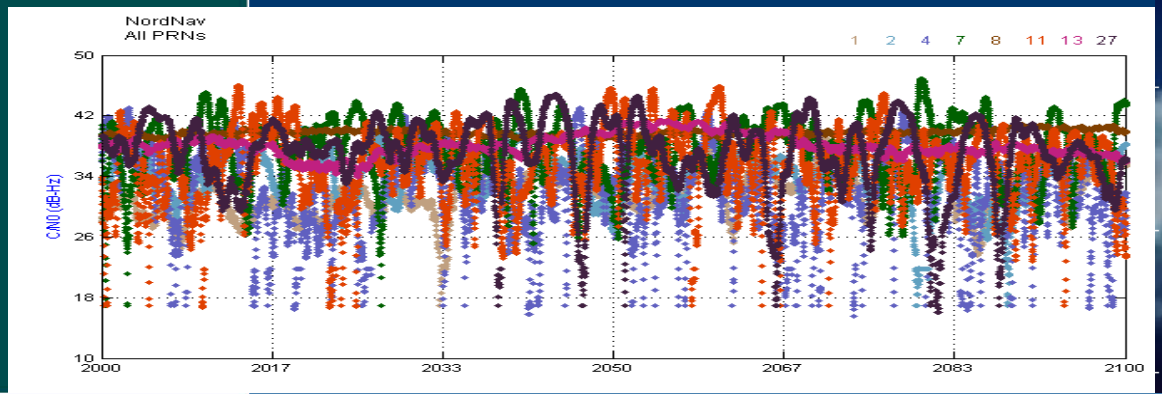
Supreme Court's GPS case asks: How much privacy do we expect?

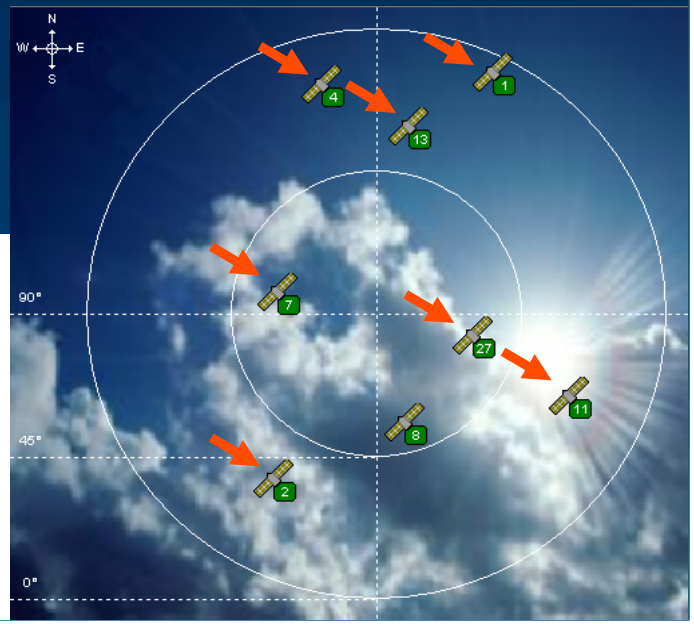
By Jonathan Turley, Published: November 11

In December 1967, the Supreme Court issued what many consider to be one of its greatest and most eloquent decisions, in *Katz v. United States*. That case, which is celebrated as saving privacy in the United States, articulated the principle that "the Fourth Amendment protects people, not places." The decision reversed a long erosion of privacy protection and required greater use of warrants by the government.

Ionospheric Scintillation







Regions with Scintillation

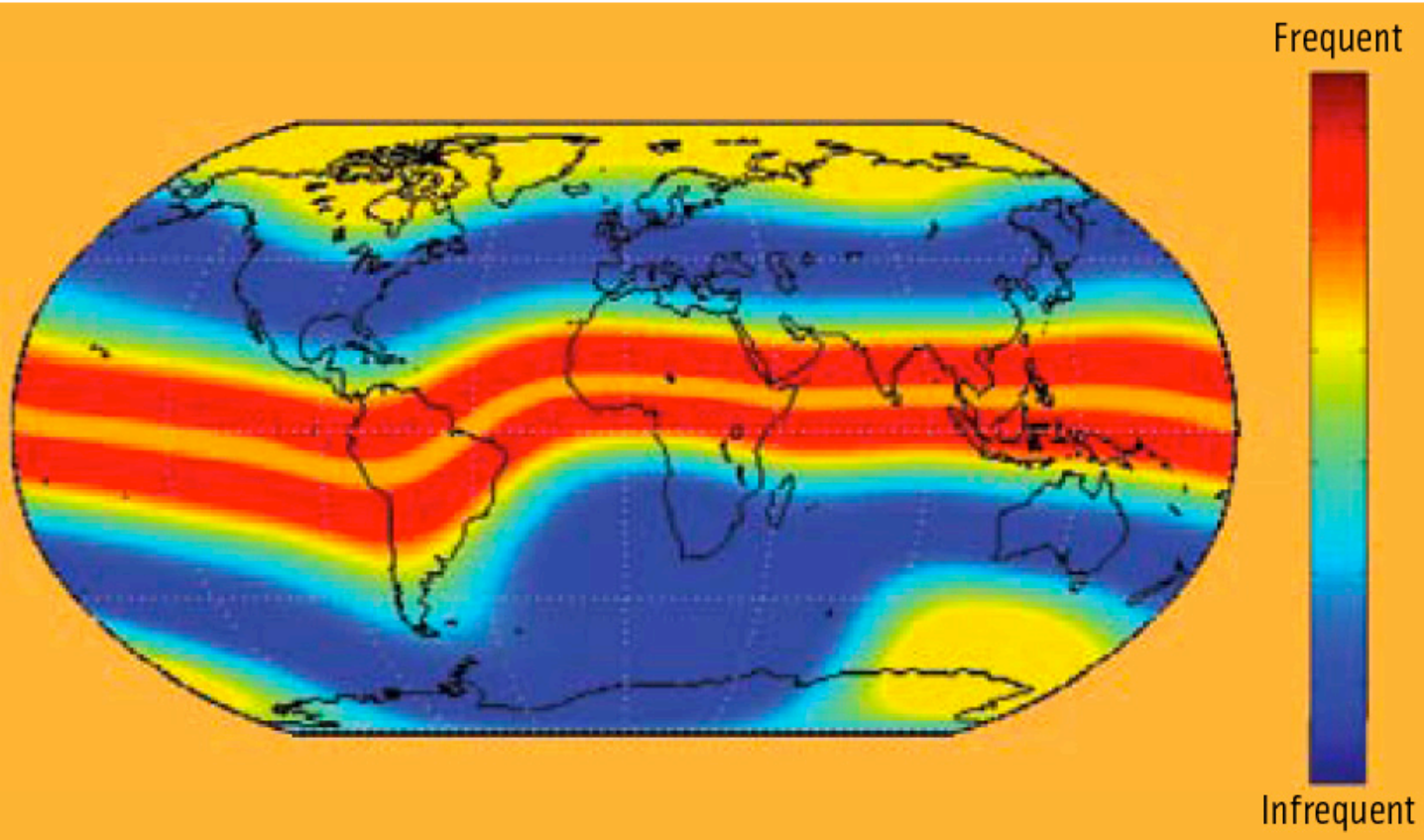
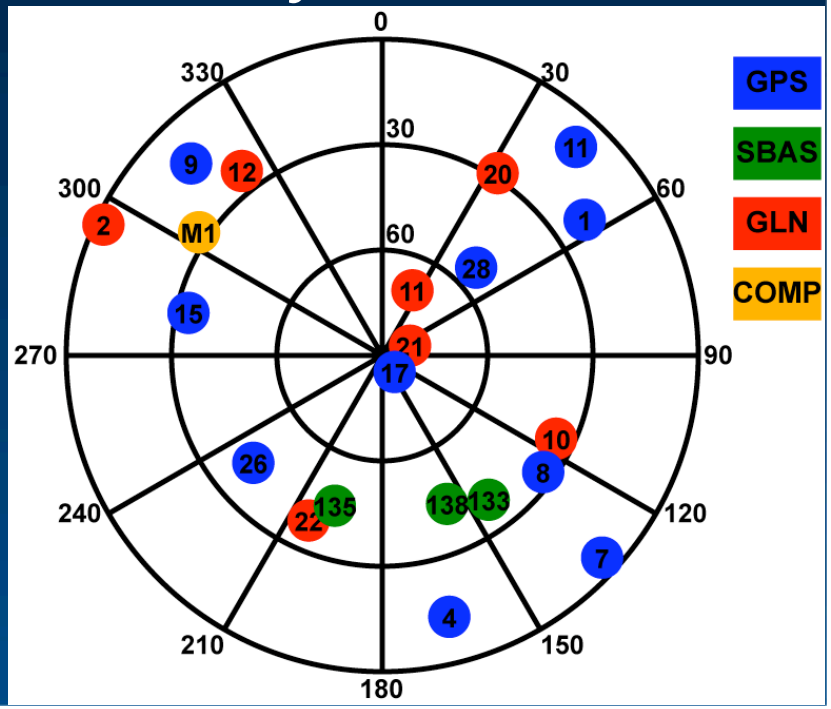


FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.

Courtesy: Paul Kintner

New GNSS Constellations

- A solution to constellation weakness
  - *Many more ranging sources*
  - *Fills in gaps*
  - *Provides extra redundancy*
  - *Averages down uncertainty*



Multiple Frequencies

- GPS is adding new civil frequencies
  - *Including L5 (in an aviation band)*
- Other constellations also including signals at or near L1 and L5
- Two frequencies allow direct removal of ionospheric delay error
  - *Ionospheric scintillation may still cause loss of continuity in equatorial areas*
- Offers protections against unintentional RFI and PPDs

Advanced RAIM (ARAIM)

- Dual Frequency - Multi-constellation
  - *Eliminates multiple SV iono threat*
  - *Strong geometries*
- Support for vertical guidance
  - *Requires a more stringent level of certification than RAIM for lateral*
  - *May require ground monitoring by approving agency*
- Potential for near global coverage
  - *Modest infrastructure requirements*

GBAS

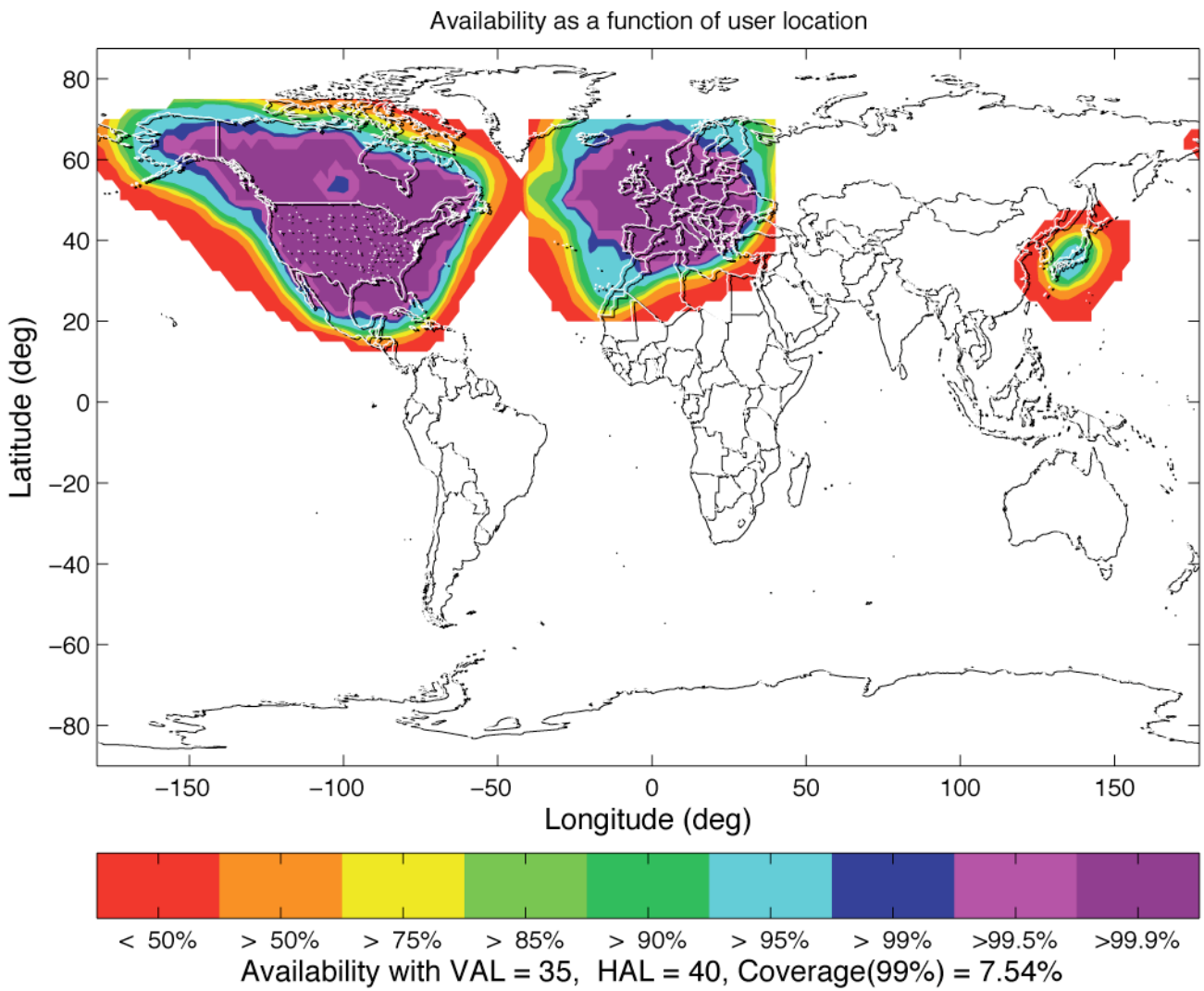
- Currently, GBAS is focusing on obtaining CAT-III service with single-frequency, GPS-only equipment
  - *Desire for service in near term*
- Multiple frequencies and multiple constellations can provide higher availability

Current SBAS Coverage

WAAS

EGNOS

MSAS

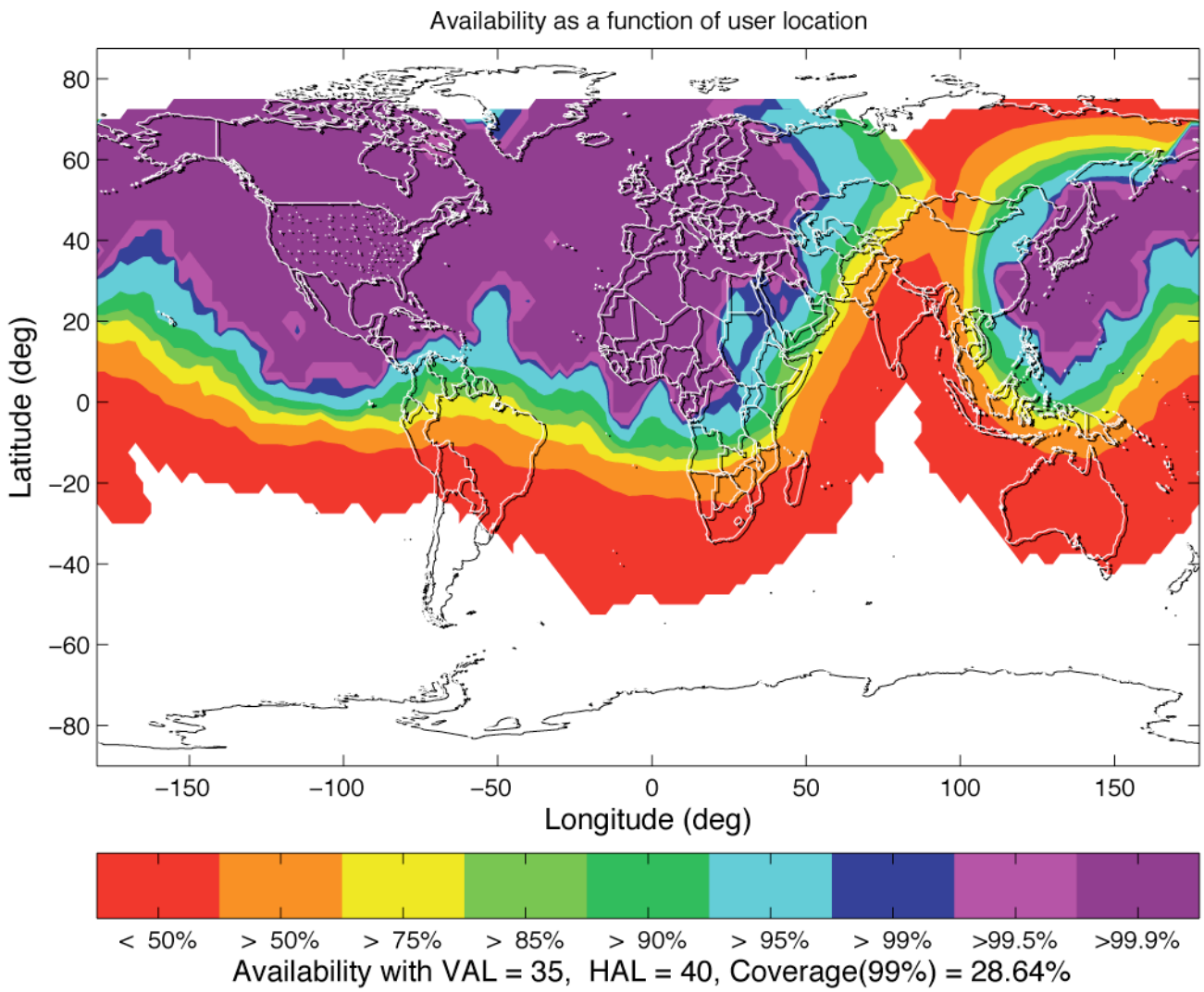


Dual Frequency Coverage (WAAS, EGNOS, MSAS)

WAAS

EGNOS

MSAS



Dual Frequency Coverage (with GAGAN + Russia)

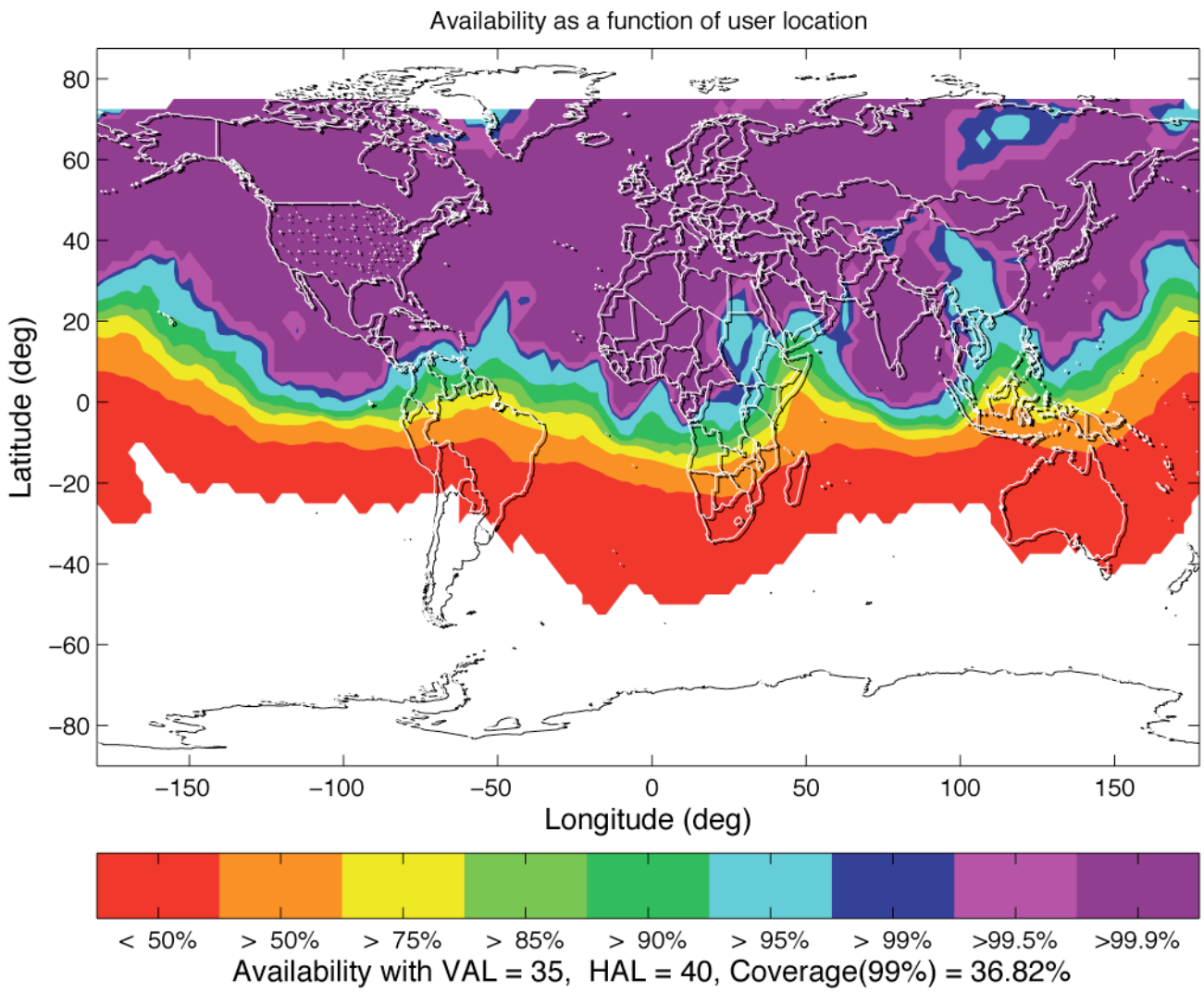
WAAS

EGNOS

MSAS

GAGAN

SDCM



Dual Frequency + Second Constellation (Galileo)

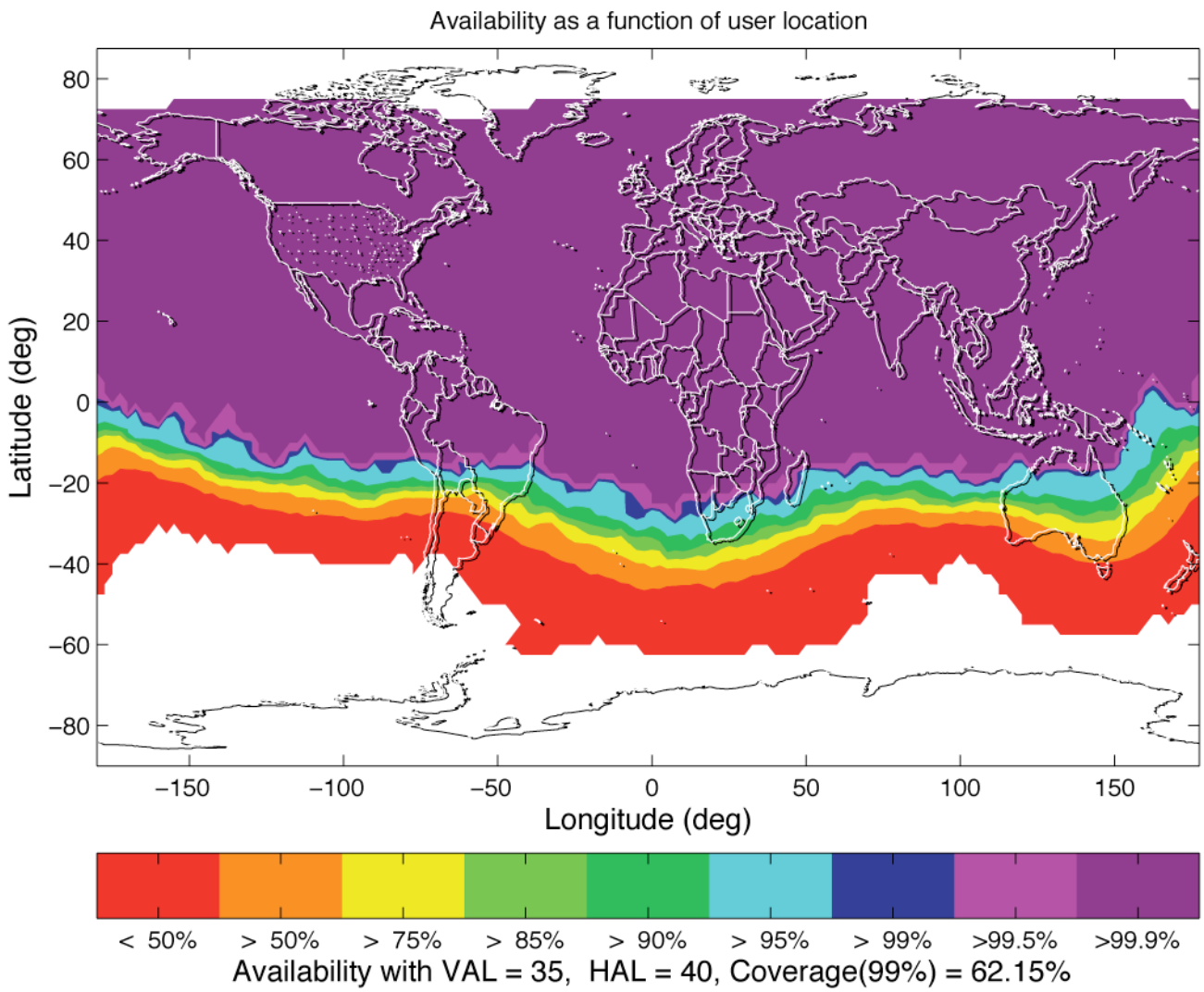
WAAS

EGNOS

MSAS

GAGAN

SDCM



Dual Frequency, Dual GNSS, Expanded Networks

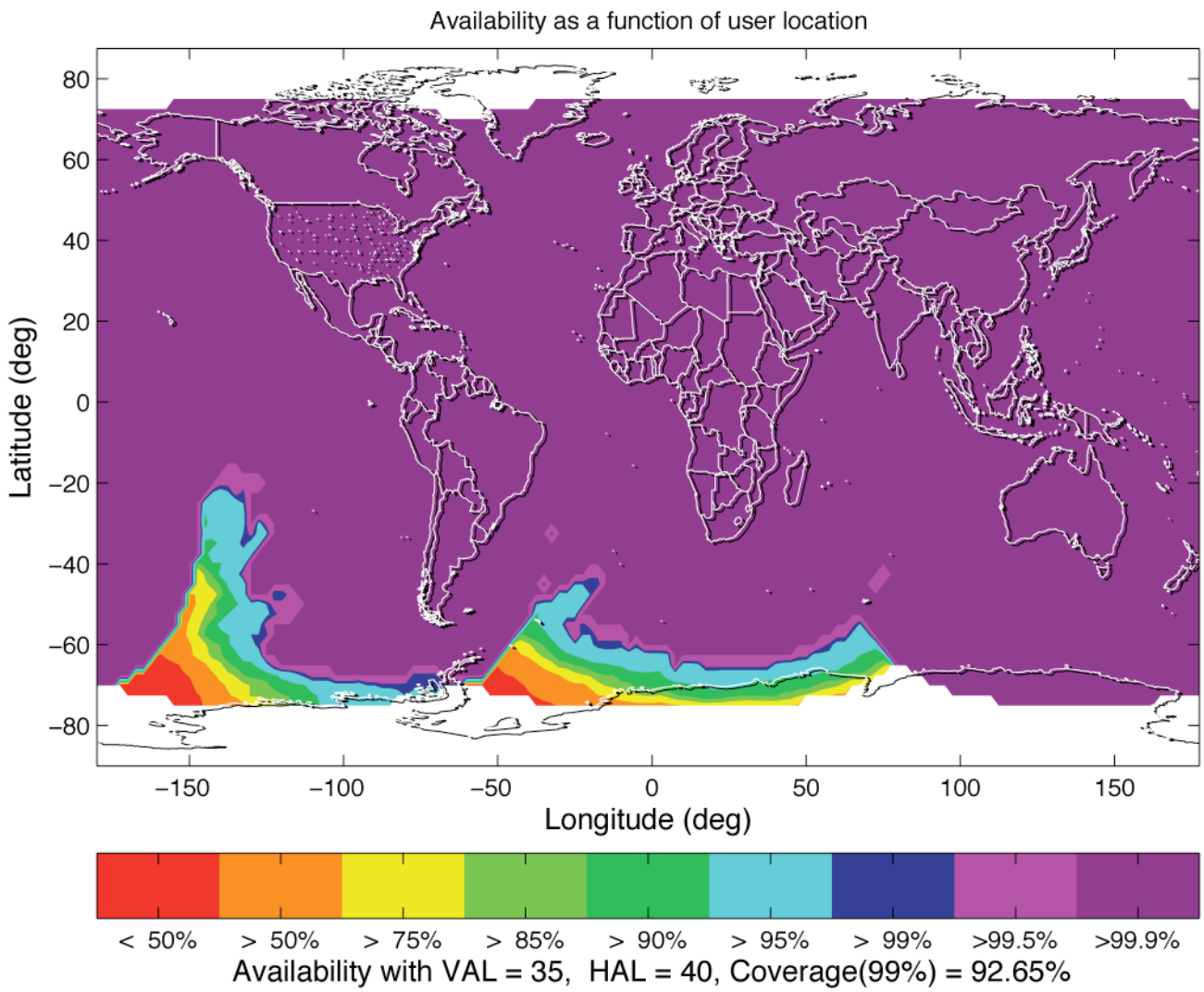
WAAS

EGNOS

MSAS

GAGAN

SDCM



Conclusion

- New aeronautical frequencies eliminate ionospheric delay threats
  - *Provides service in equatorial areas*
- Ranging signals from new constellations significantly improve user geometry
- Enormous opportunity to improve coverage and levels of service provided
- RFI and scintillation are threats that still need to be addressed
  - *Potential for mitigation through integration with other sensors*

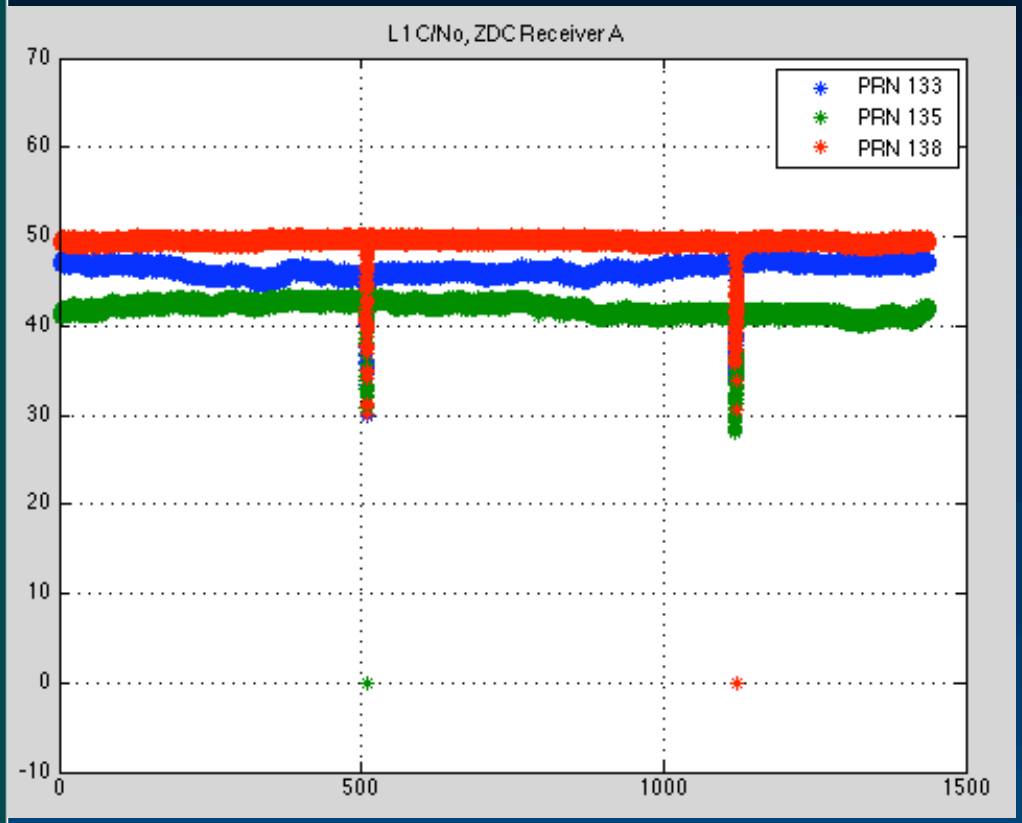
Predictions

- All three systems will incorporate multiple constellations and multiple frequencies
  - *ARAIM, GBAS, & SBAS*
  - *Different countries will choose different solutions*
    - Some will choose more than one
- There will be greater integration with other sensors
  - *Must be able to survive outages caused by RFI*

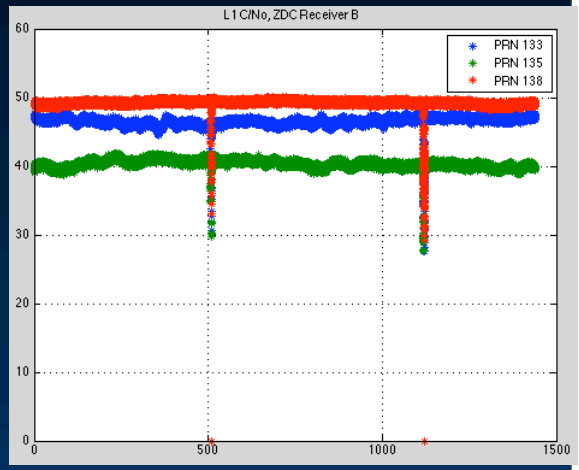
WAAS Washington DC Site

L1 C/No, WAAS GEOs

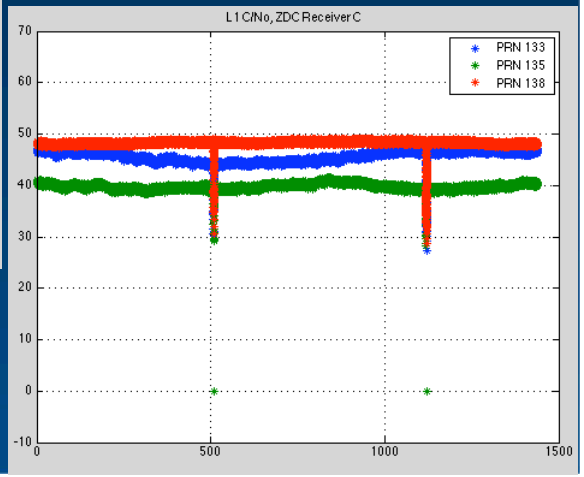
Receiver A



Receiver B



Receiver C



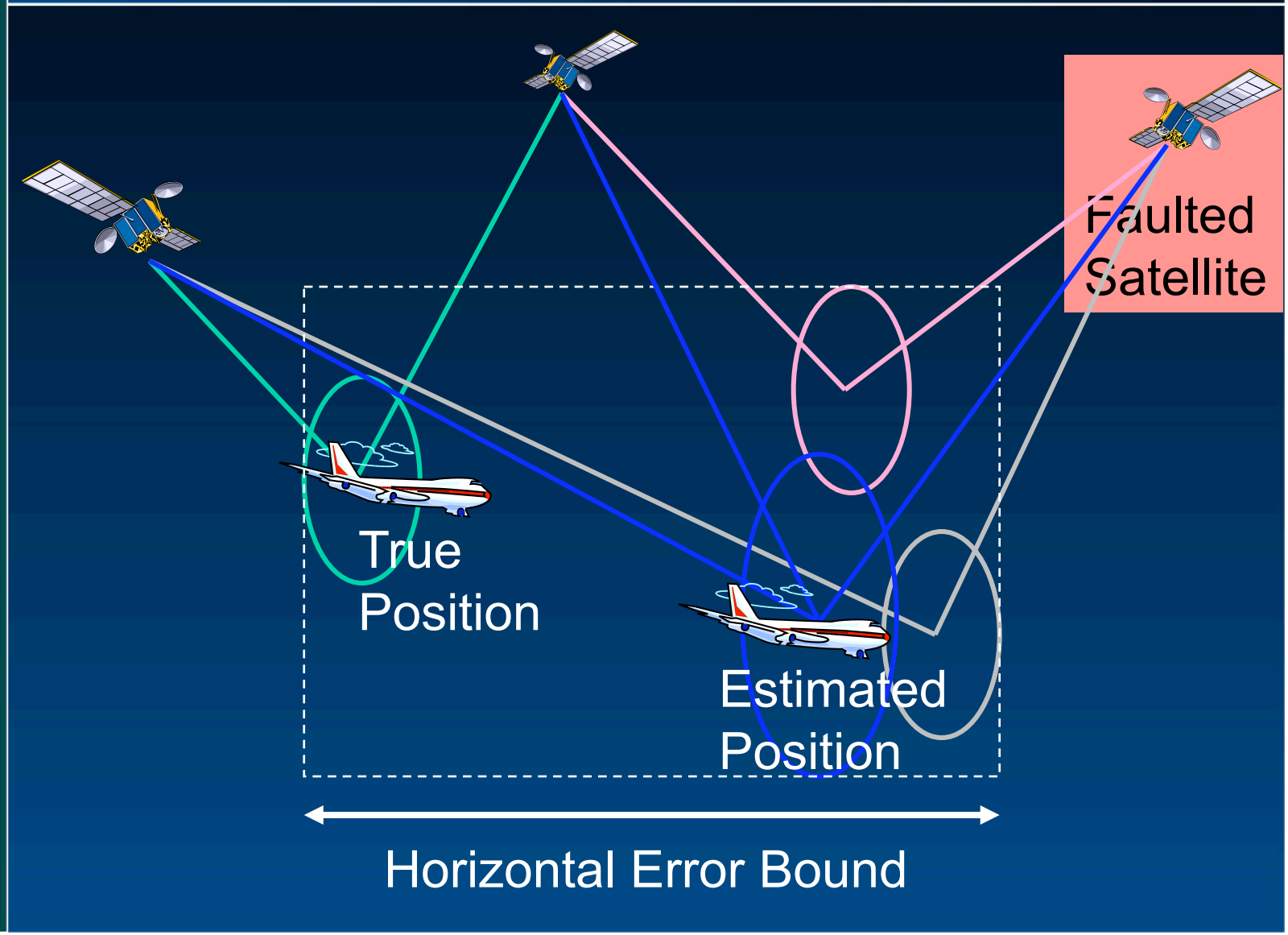
Access / Sovereign Control

- Currently only GPS used for Aviation
  - *Countries either allow it or not*
- Russian Federation has issued a mandate for use of GLONASS
  - *Other countries may follow suit*
- Countries may want to allow use of some constellations and not others
  - *Trust, liability, monitoring, …*
  - *May want method to allow some satellites, but exclude others*

ADS-B & NextGen

- ADS-B mandate effectively requires all aircraft to have GNSS by 2020
  - *May require better than basic RAIM*
- Ideally, link mandate to multi-constellation, multi-frequency receiver
  - *ARAIM, GBAS, SBAS?*
  - *Whatever does not make it in, may not be put on an aircraft for a very long time*

RAIM Protection

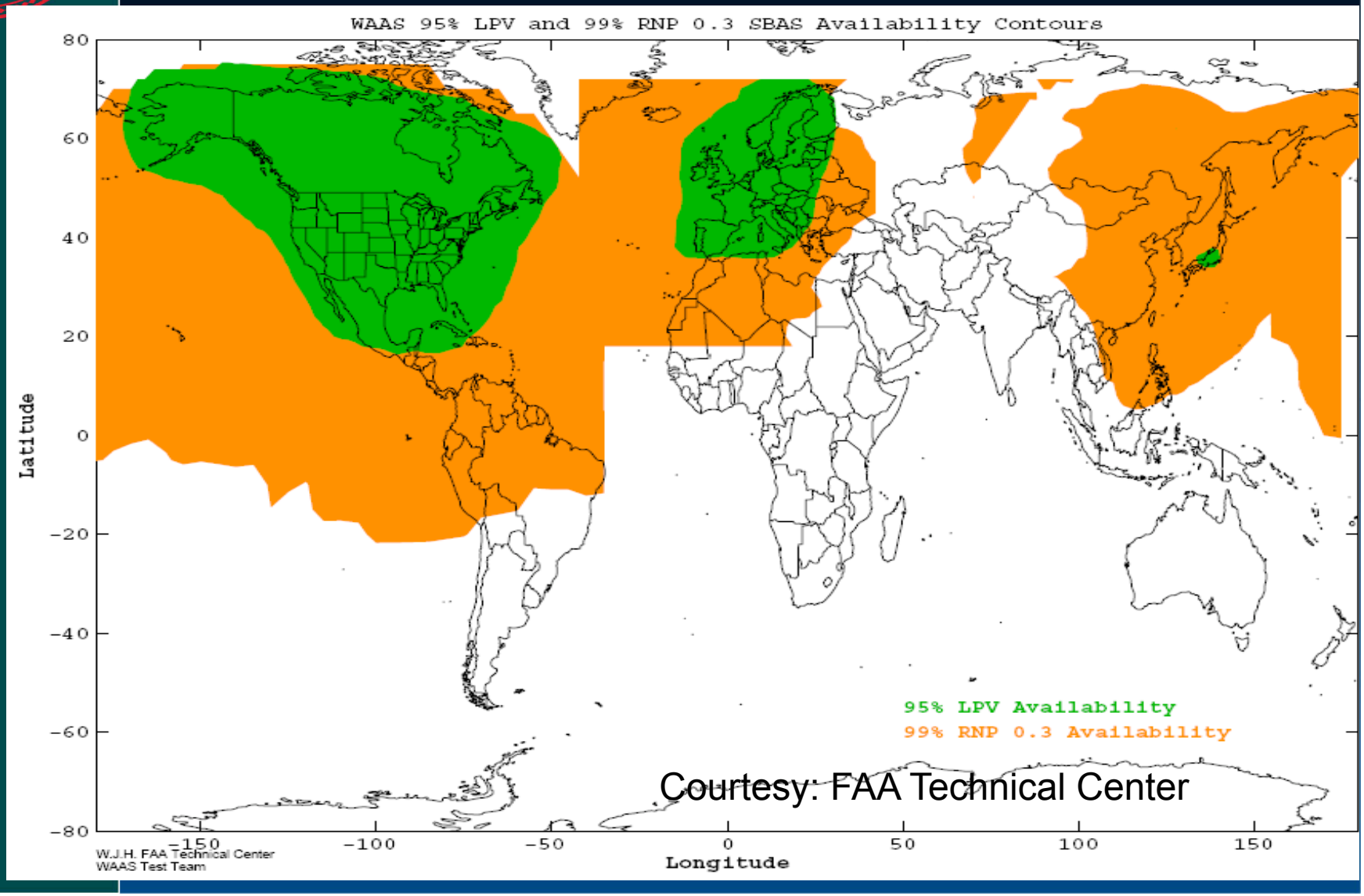


Courtesy:
Juan Blanch

Approved GPS Aviation Operations (as of 2007)

Courtesy: FAA

Current SBAS Coverage



Courtesy: FAA Technical Center