Satellite-Based Augmentation System (SBAS) Integrity Services

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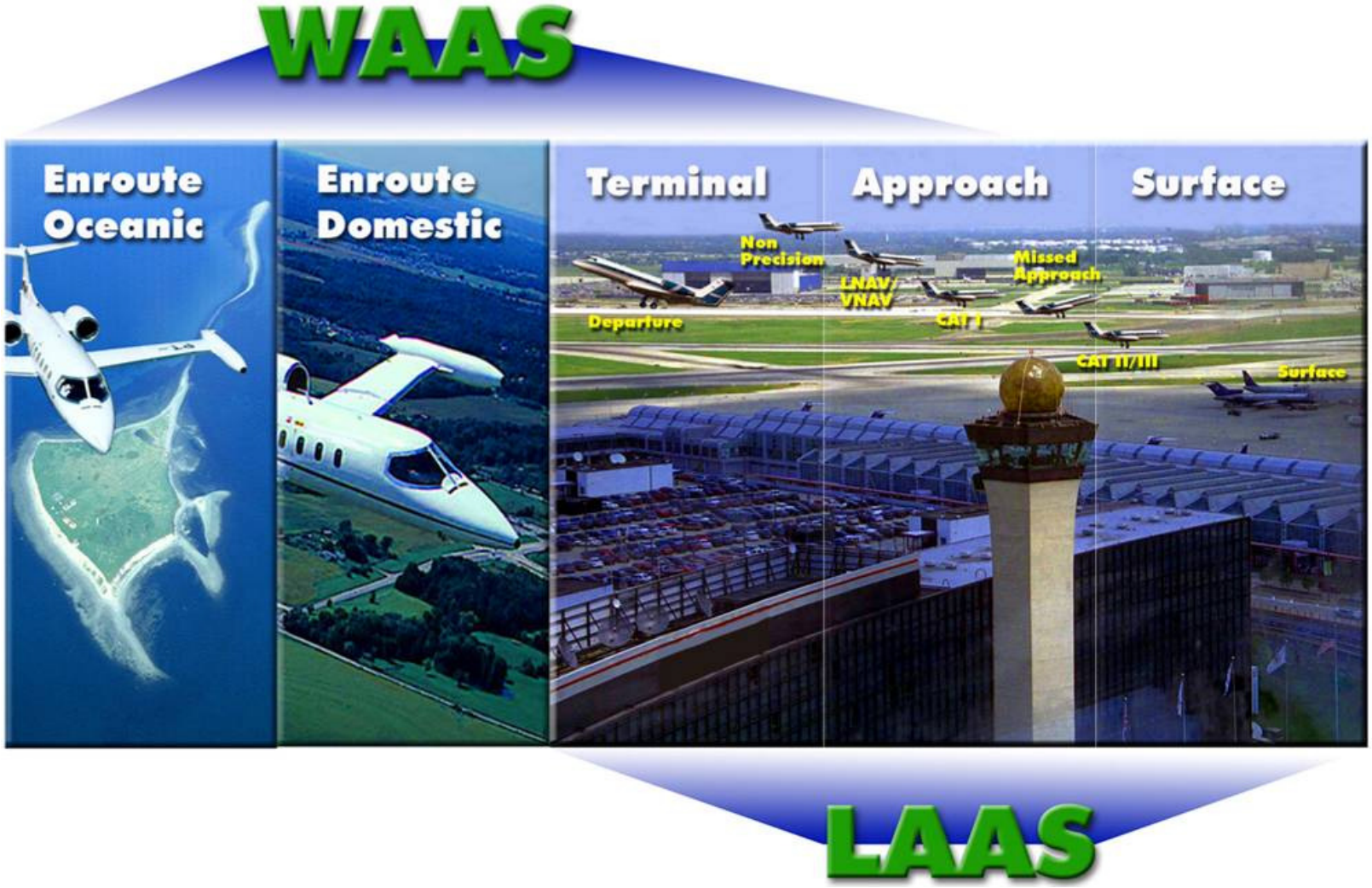
FAA Satellite Navigation Program

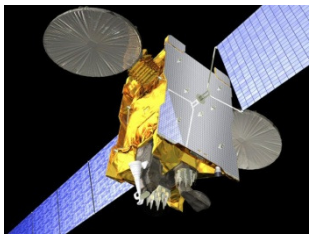


Wide Area Augmentation System - 2003

38 Reference Stations

3 Master Stations

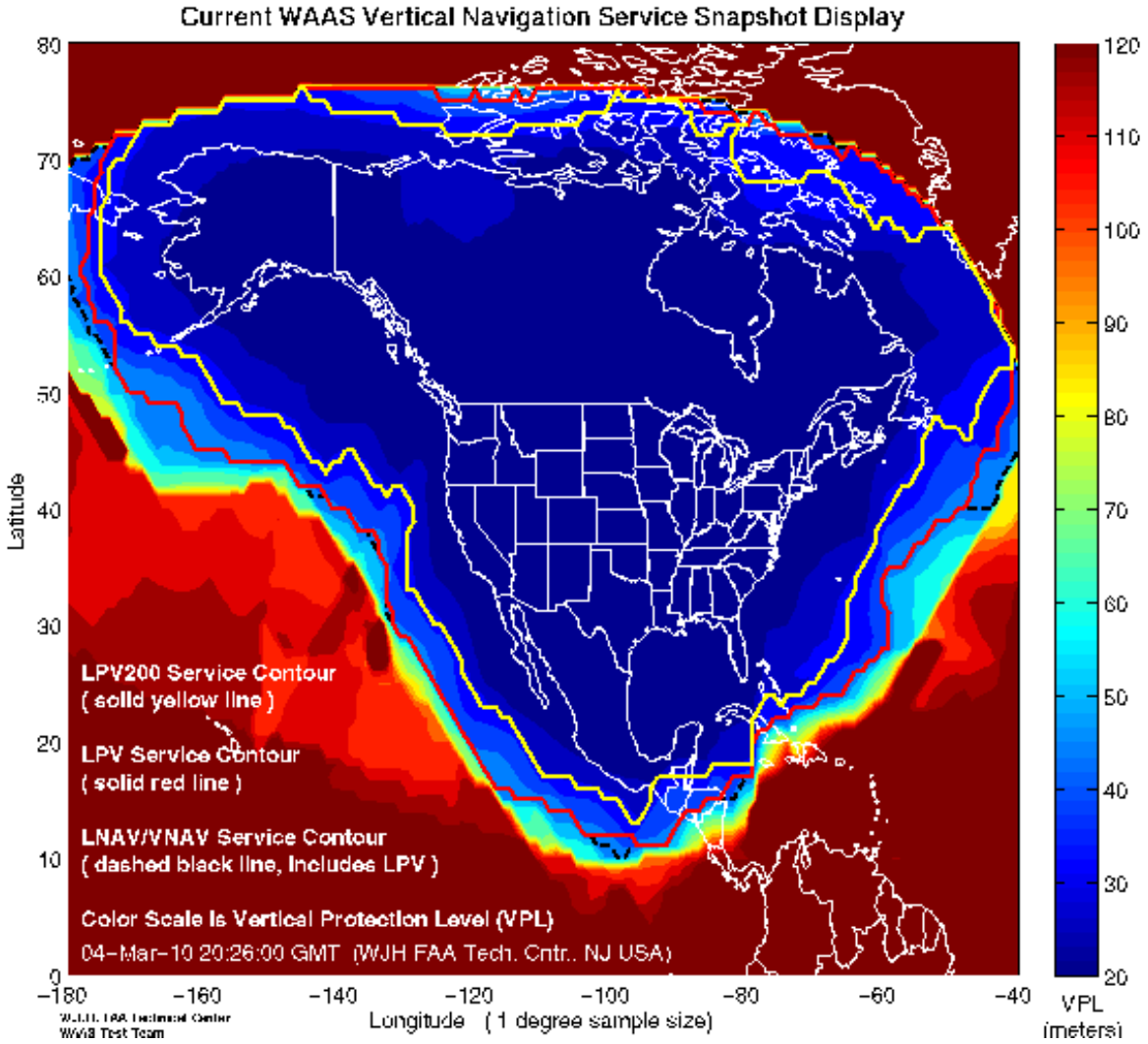
4 Ground Earth Stations



2 Geostationary Satellite Links

2 Operational Control Centers

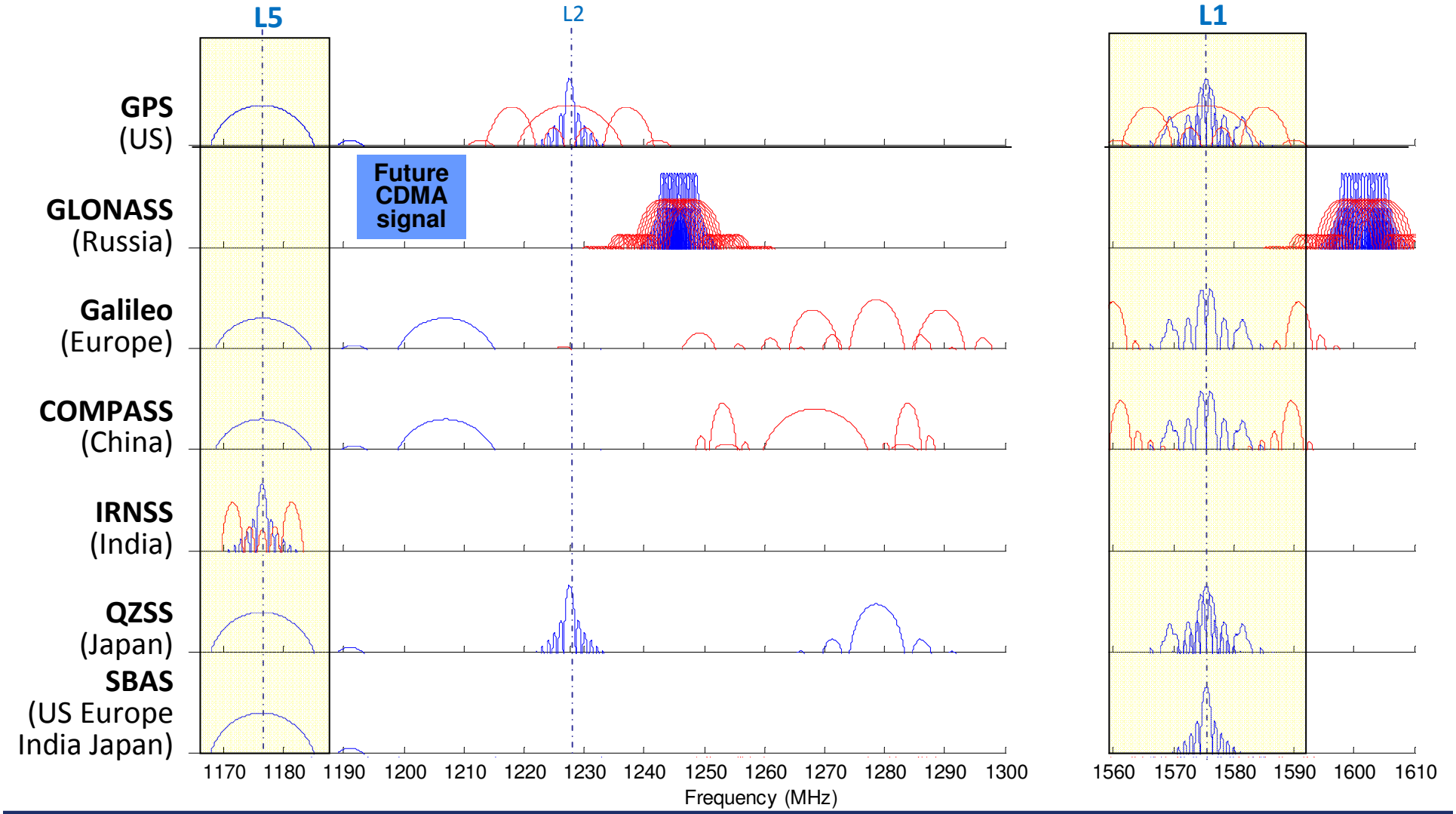
WAAS LPV Coverage



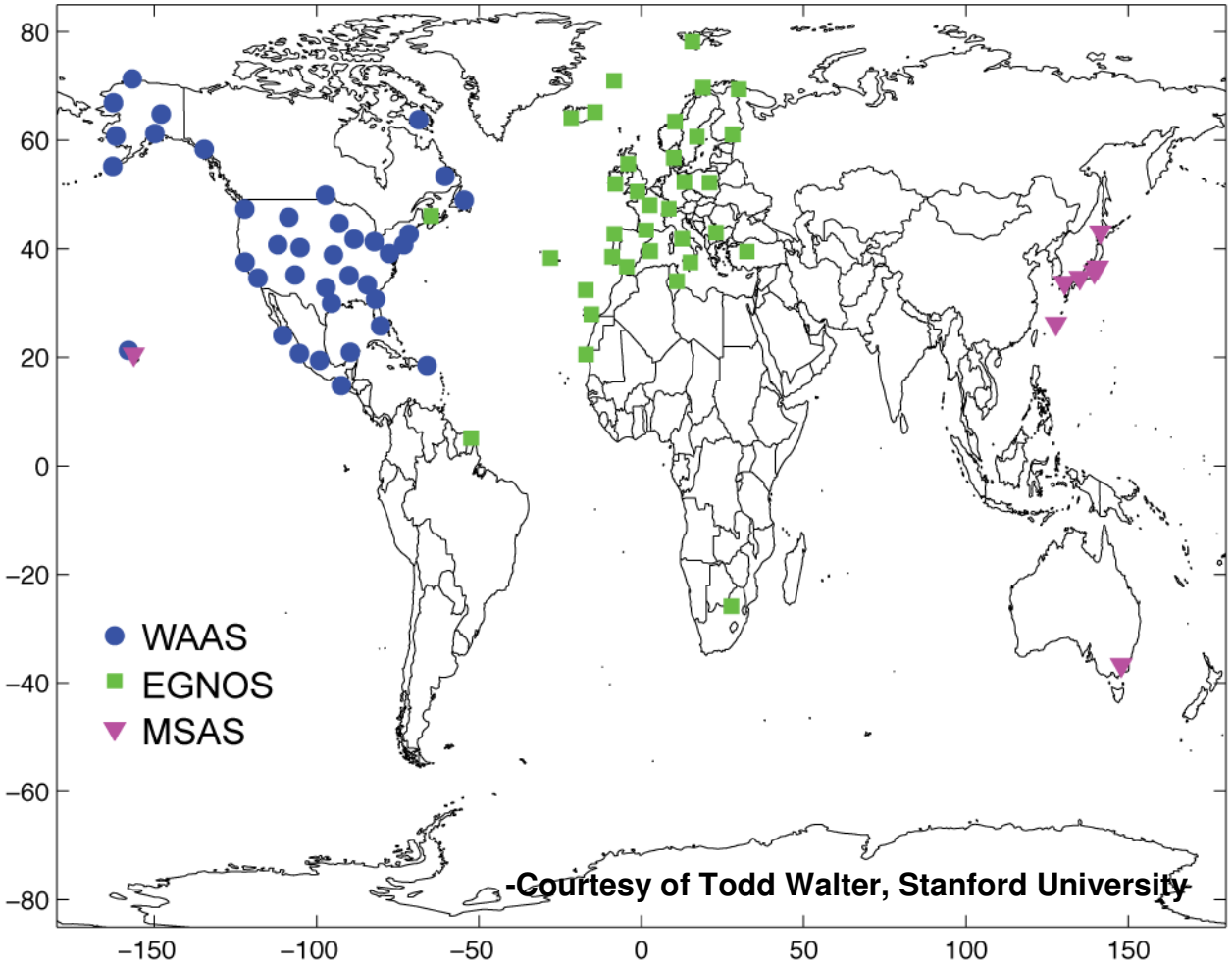
SBAS Future Considerations

- **Dual Frequency GNSS Services in protected aeronautical bands**
  - Enables direct estimation and removal of ionospheric delay errors
  - Single largest source of vertical position uncertainty
- **Most significant remaining threats are satellite failure based**
  - Design a new VPL equation targeting single satellite faults
- **New SBAS being developed by India and Russia**
- **Investigate potential to expand LPV to global coverage**

Current International Signal Plans



Current Reference Networks



-Courtesy of Todd Walter, Stanford University

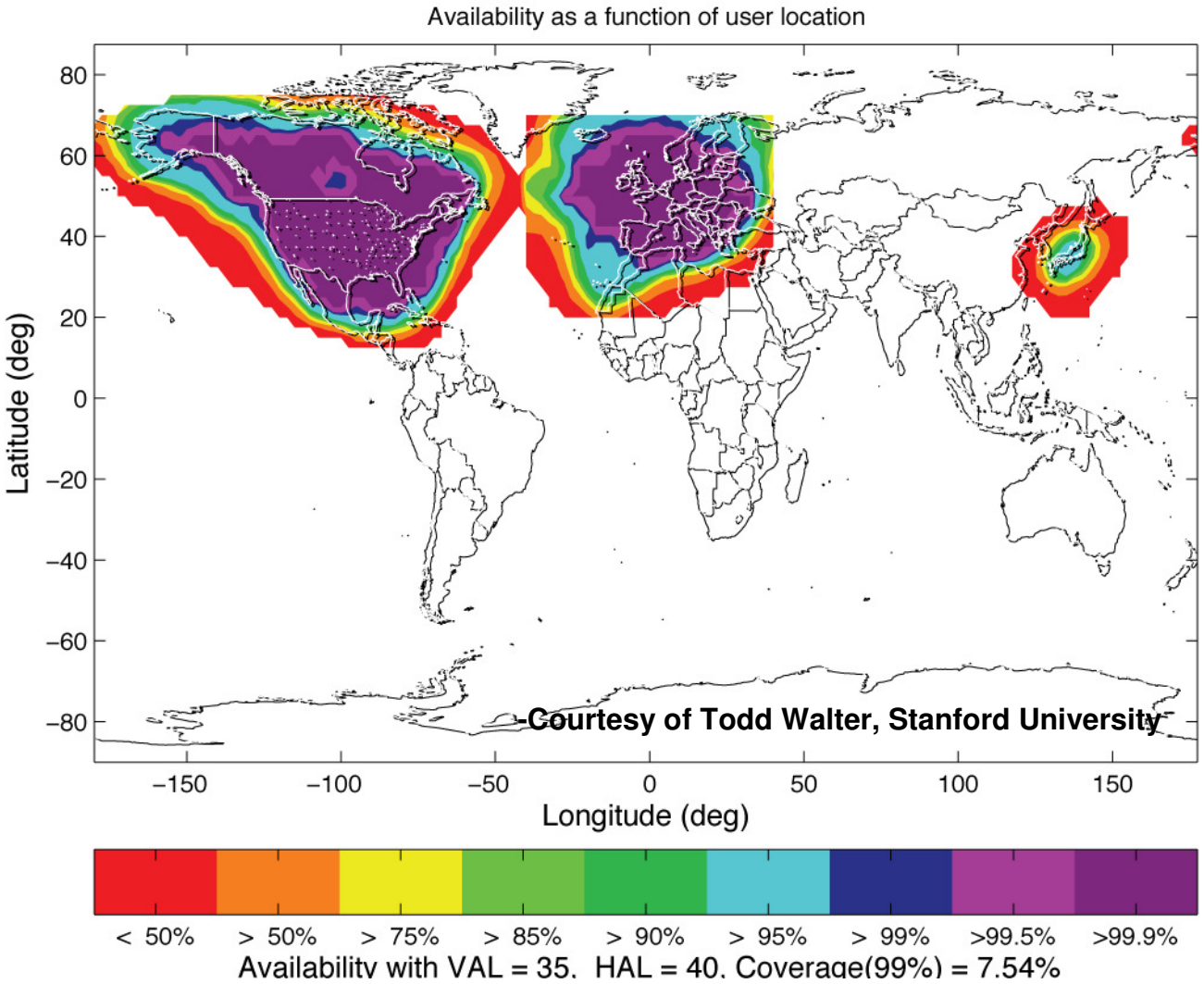
LPV-200 Coverage Estimated

(Single Frequency GPS)

WAAS

EGNOS

MSAS



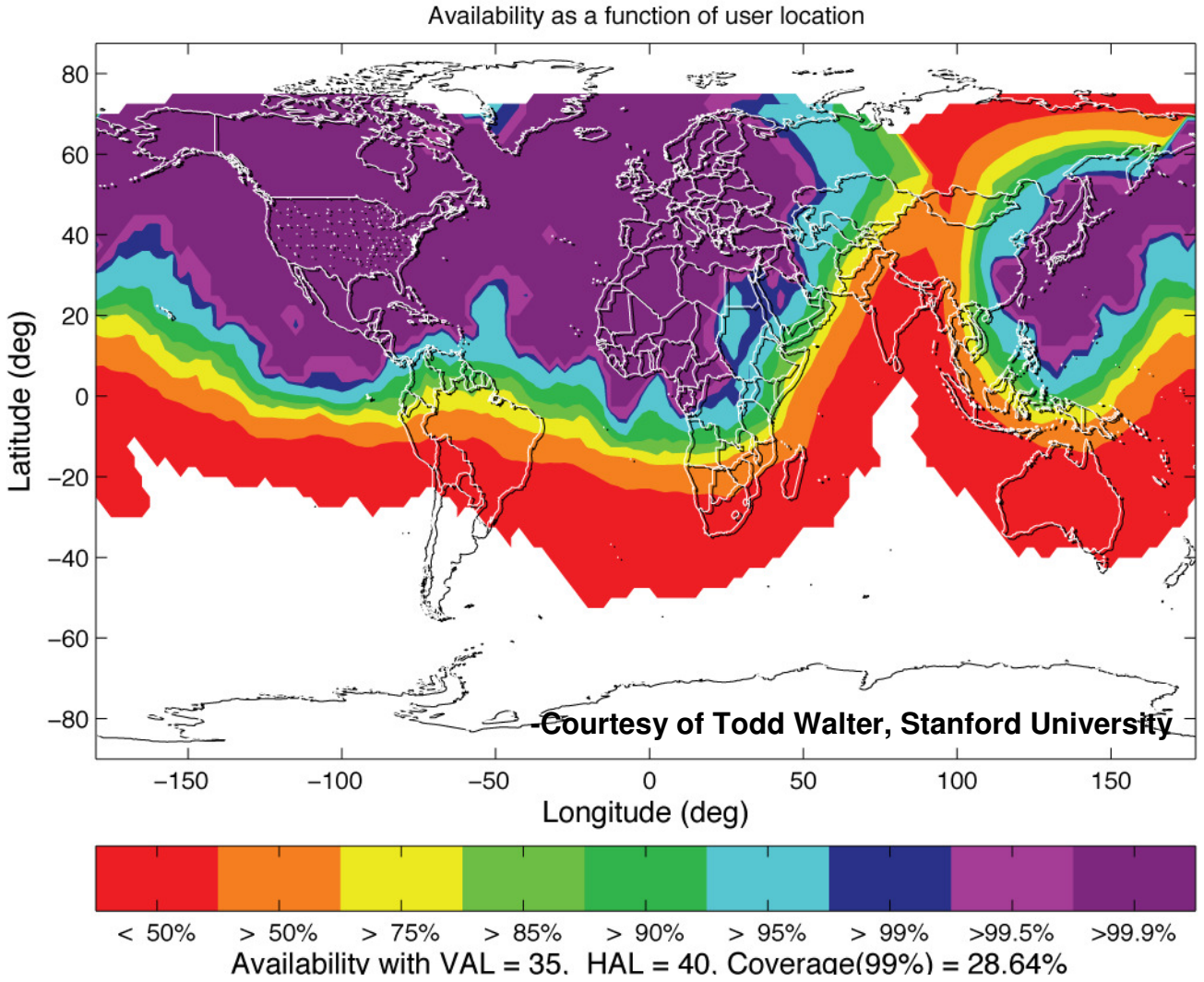
Future LPV-200 Coverage

(Dual Frequency GPS)

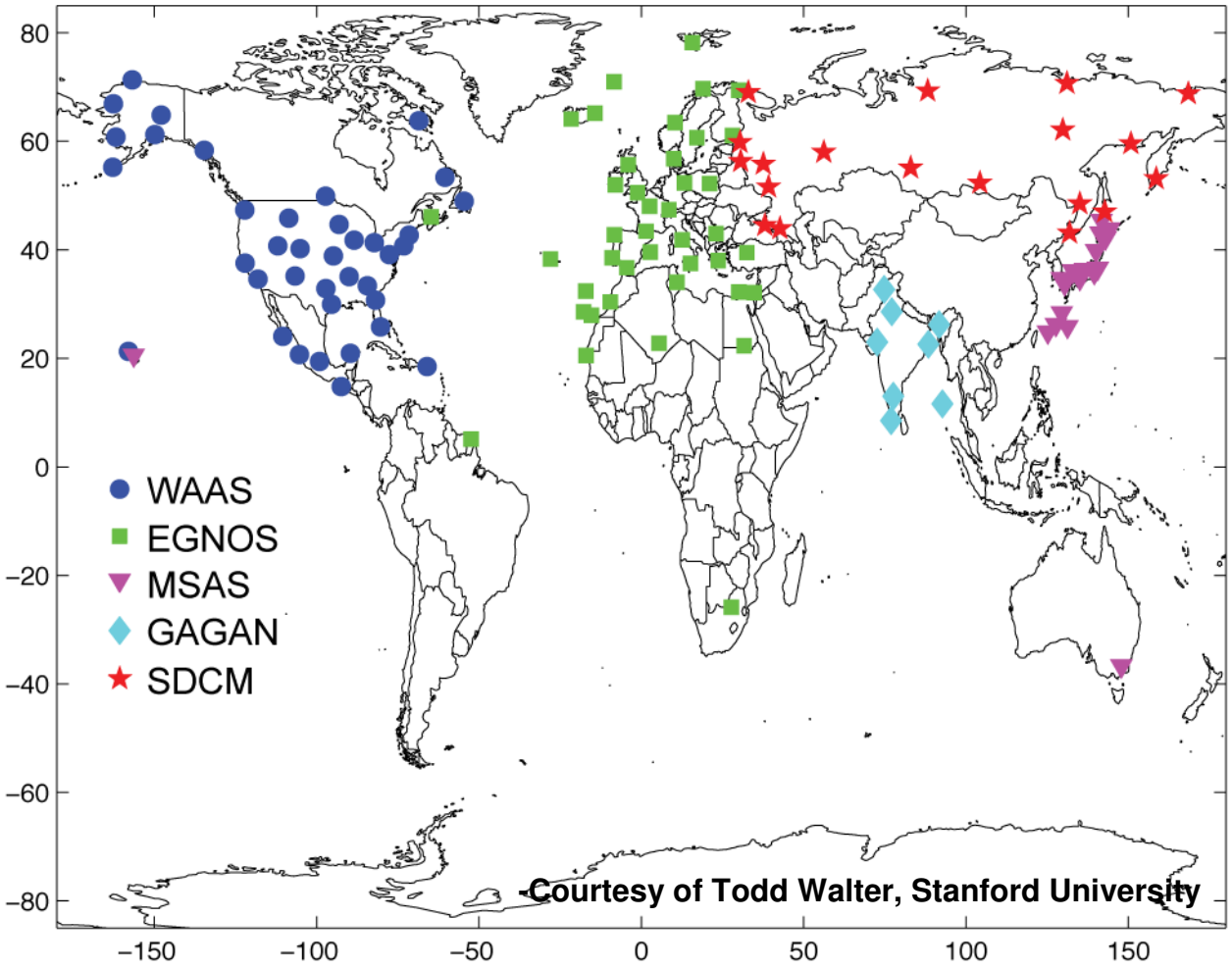
WAAS

EGNOS

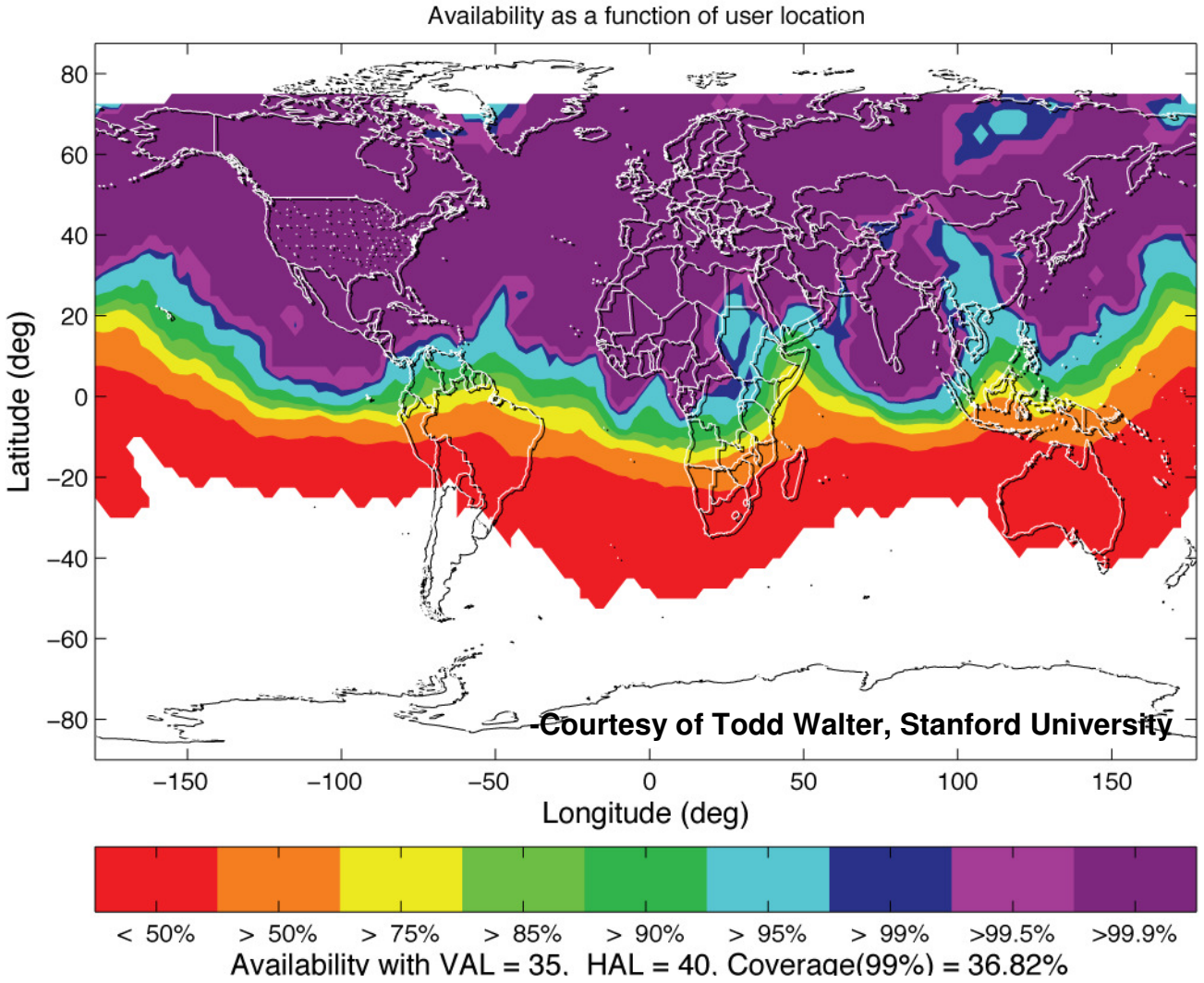
MSAS



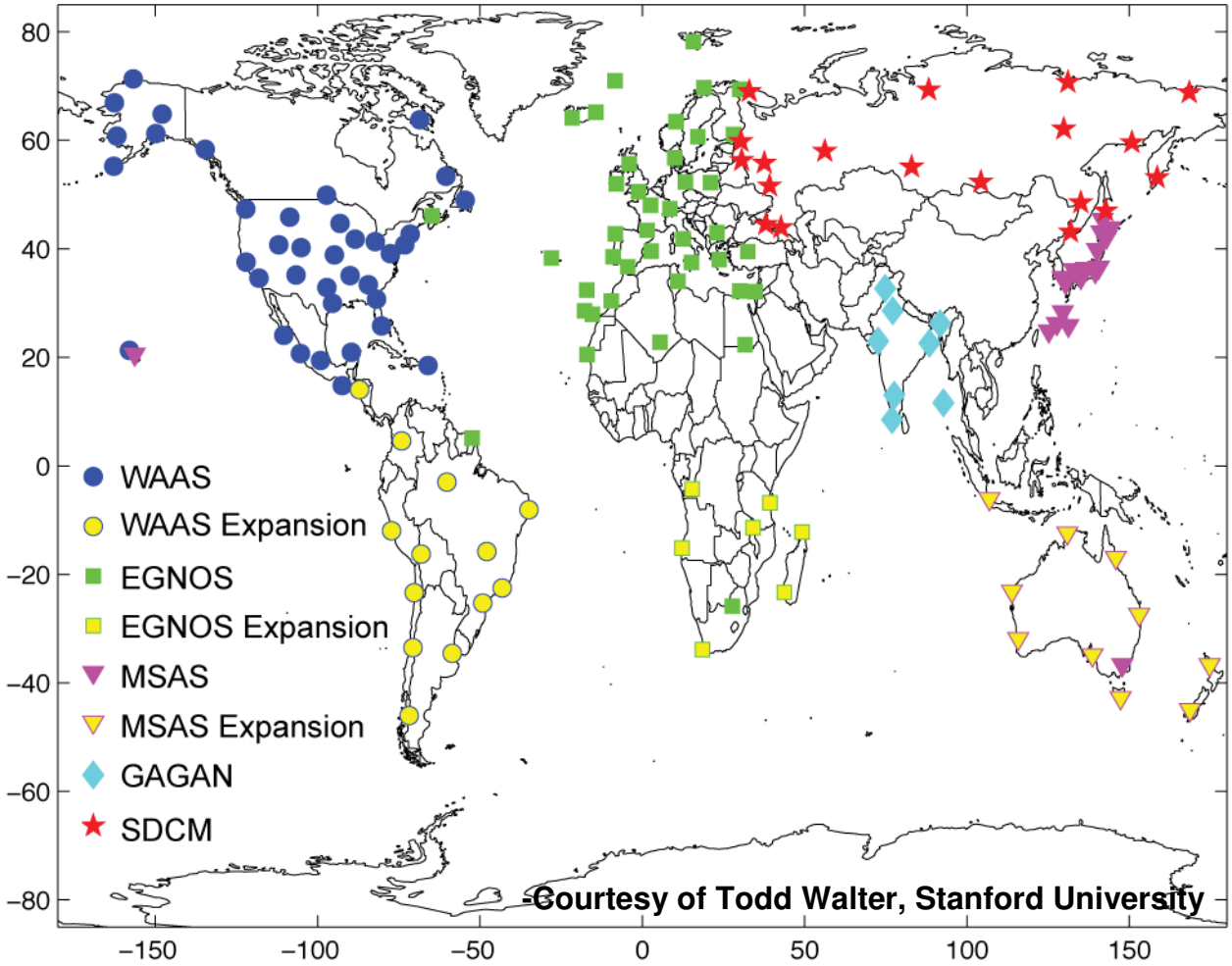
WAAS, MSAS, EGNOS, GAGAN and SDCM Reference Networks



WAAS, MSAS, EGNOS, GAGAN & SDCM
(Dual Frequency GPS)

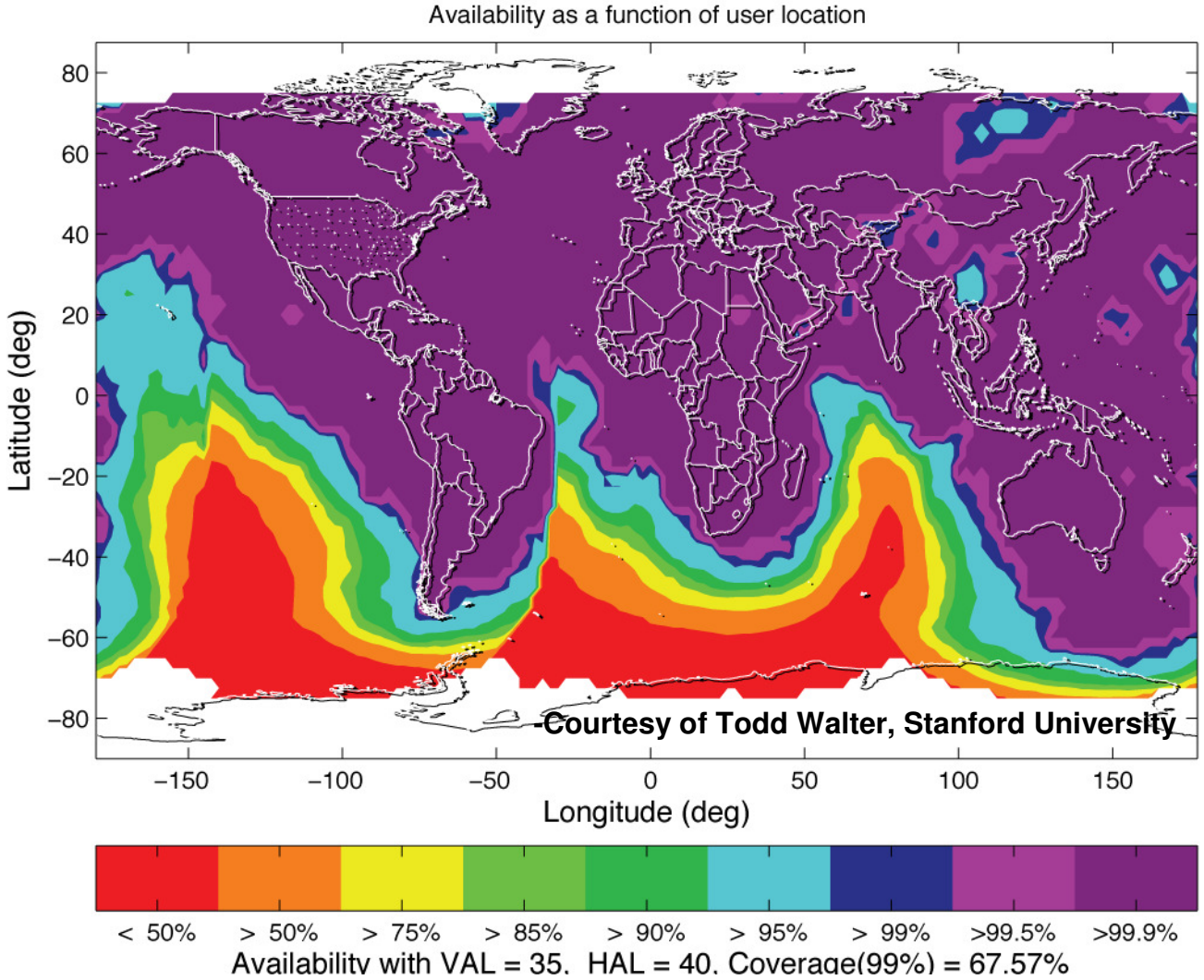


Expanded Networks



WAAS, MSAS, EGNOS, GAGAN & SDCM

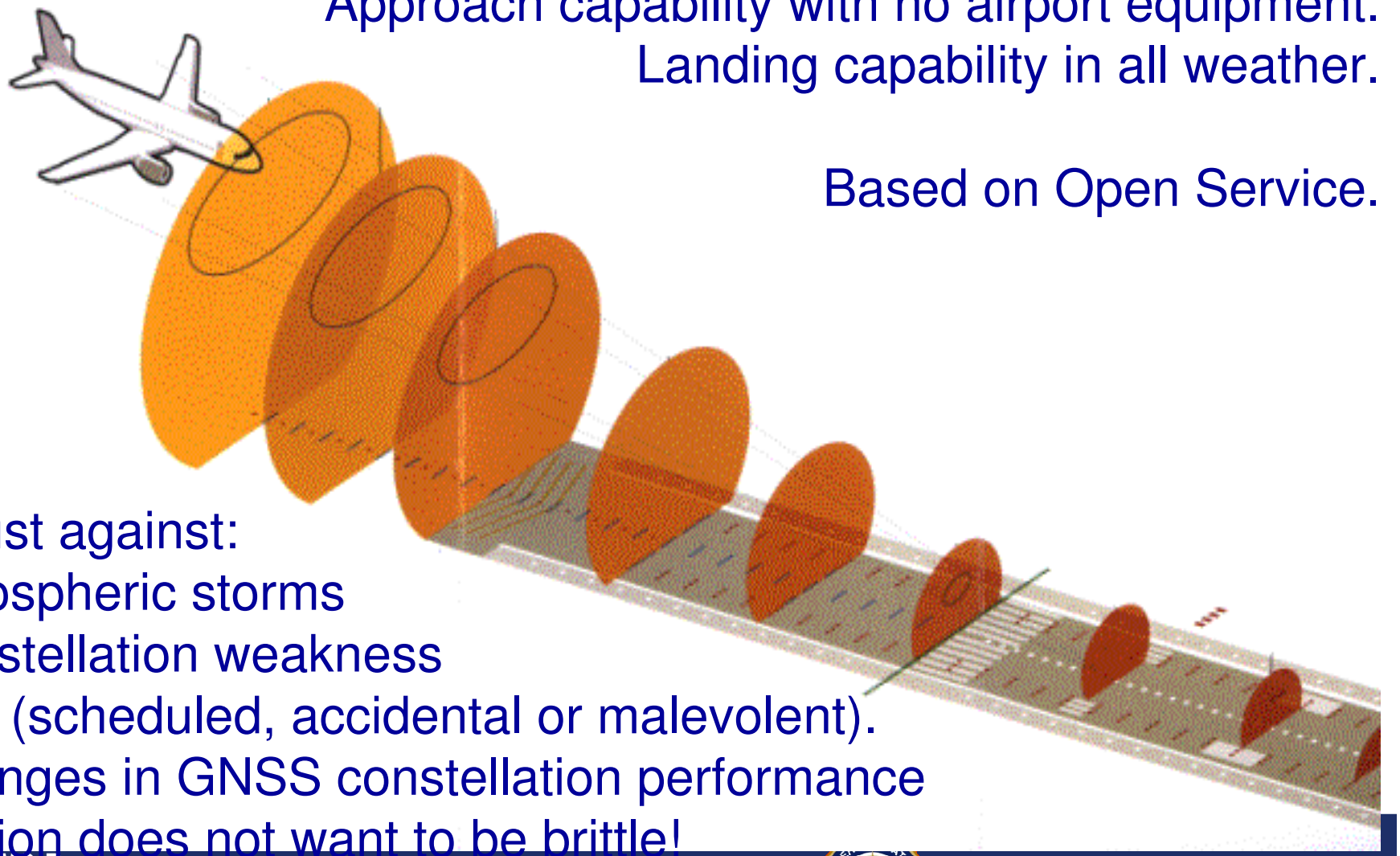
(Dual Frequency GPS + Expanded Networks)



Objective: Worldwide Approach & Landing

Approach capability with no airport equipment.
Landing capability in all weather.

Based on Open Service.

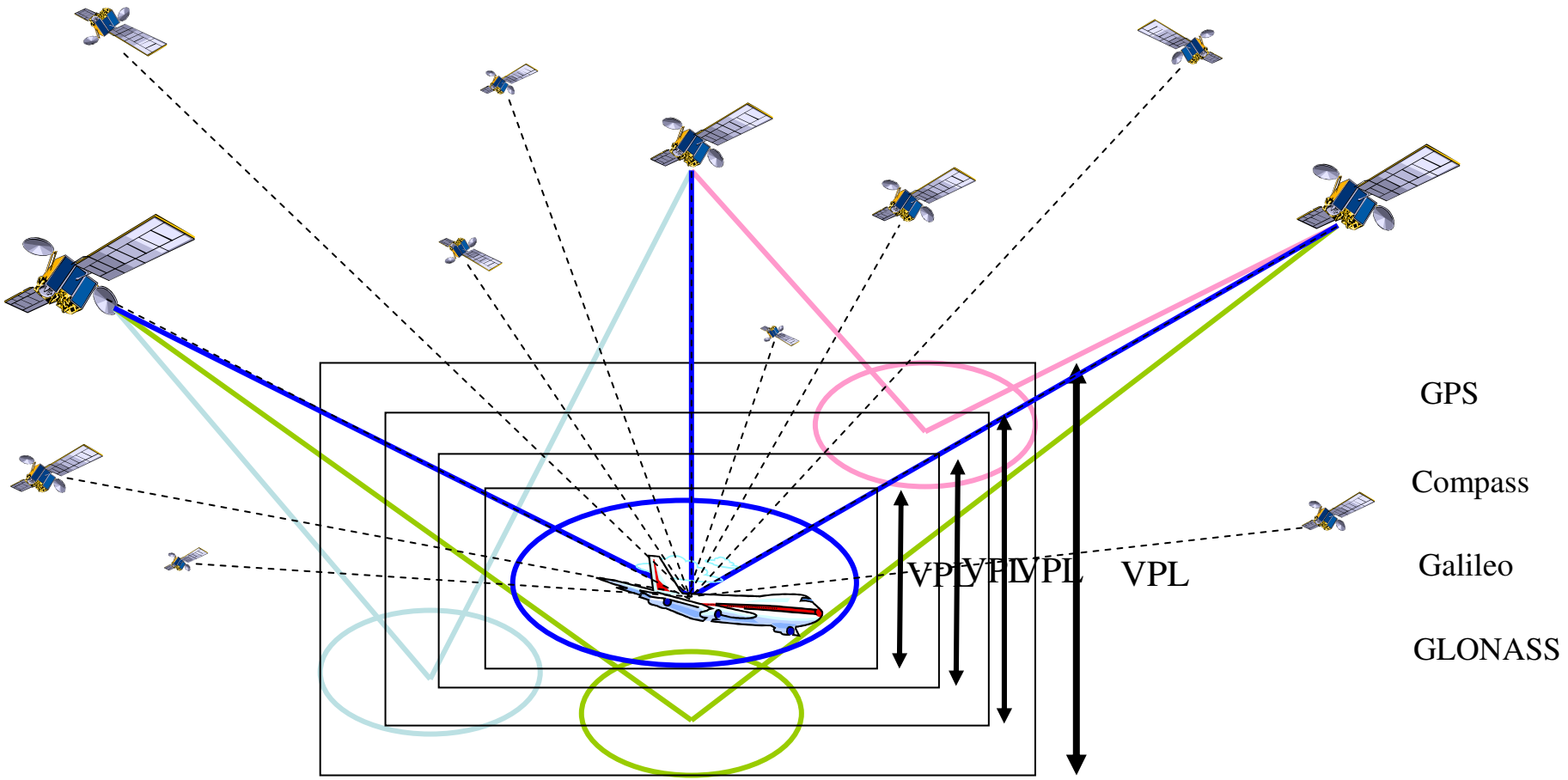


Robust against:

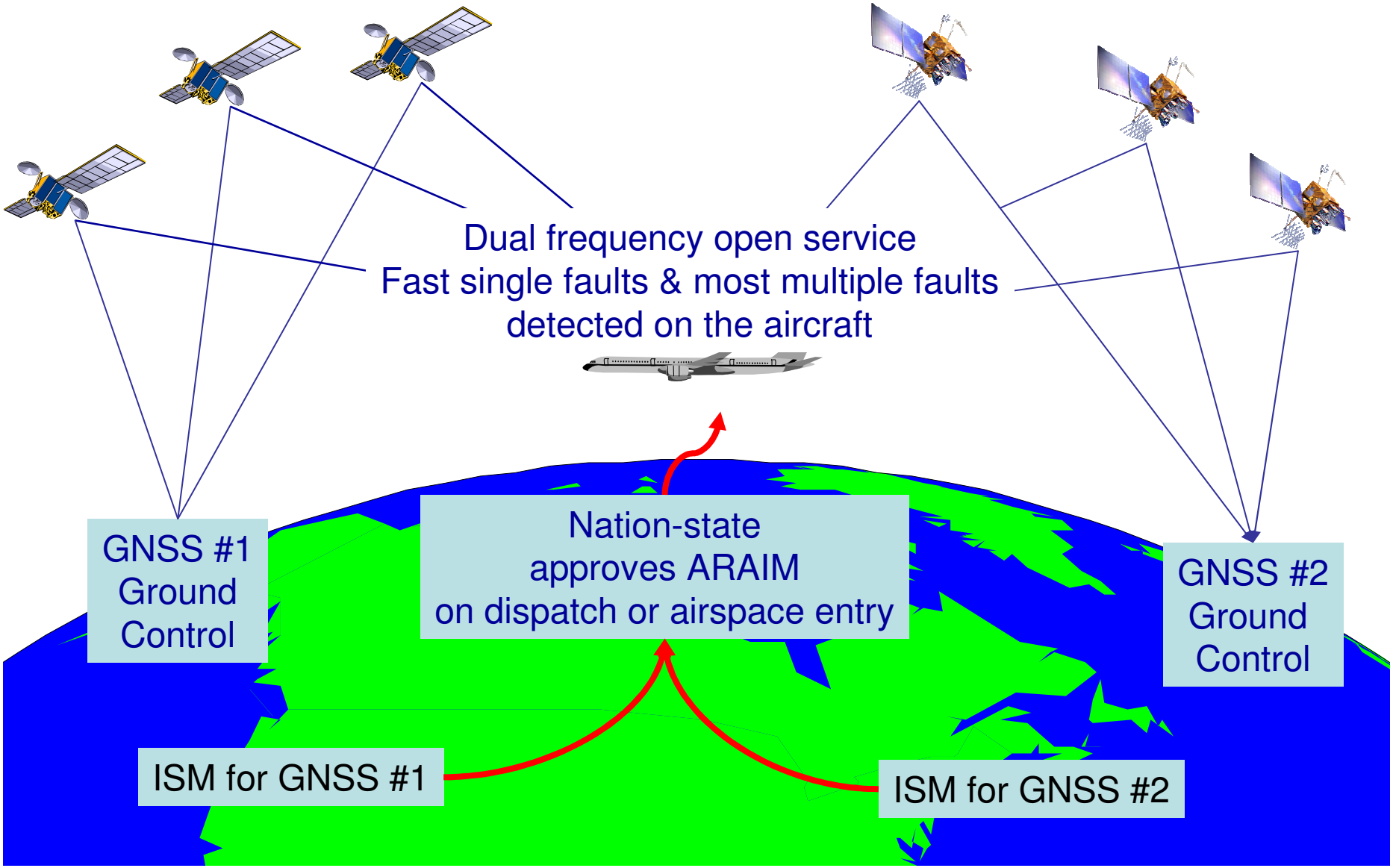
- ionospheric storms
- constellation weakness
- RFI (scheduled, accidental or malevolent).
- changes in GNSS constellation performance

Aviation does not want to be brittle!

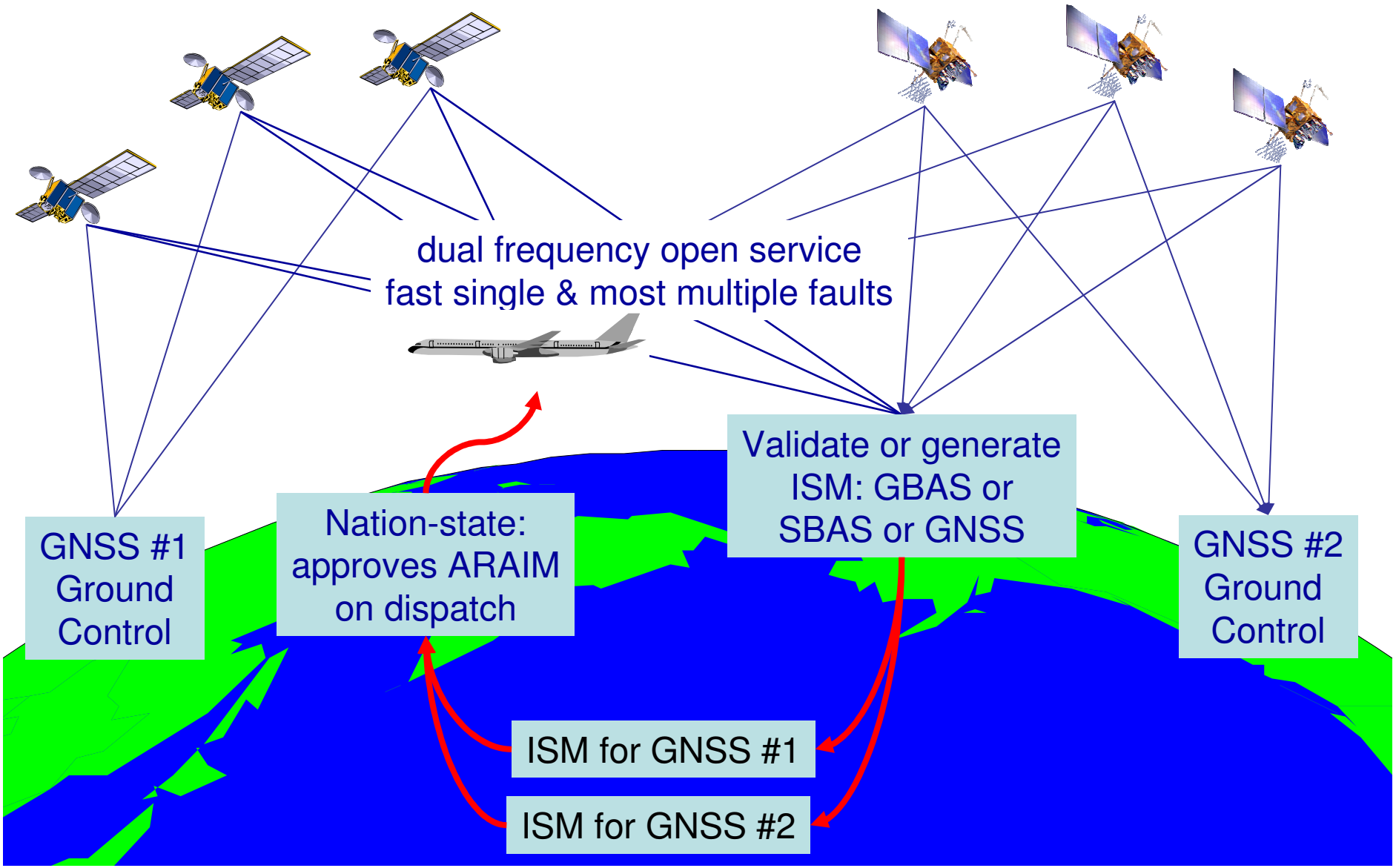
Advanced Receiver Autonomous Integrity Monitoring (ARAIM)



Advanced RAIM (ARAIM) + Integrity Support Message (ISM)



Who provides or validates the Integrity Support Message?



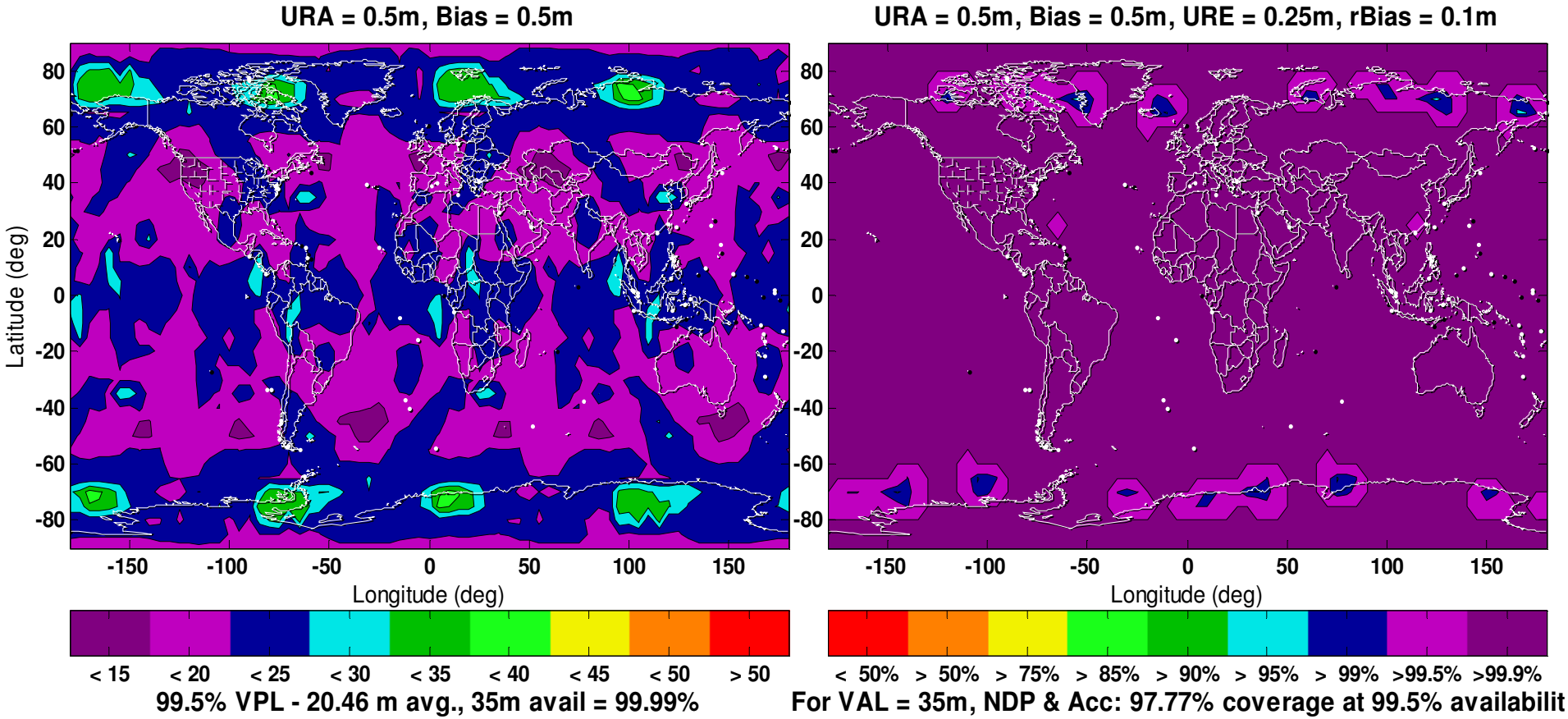
Worldwide Coverage for LPV-200 & ARAIM Availability of 99.5% Weak Constellation: 21 GPS & 24 Galileo

failure prone satellites →

weaker satellites ↓

	10^{-5}	10^{-4}	10^{-3}	10^{-2}
URA = .5 m URE = .25 m Bias = .75 m	100%	99.8%	98.6%	**57%**
URA = 1 m URE = .5 m Bias = .5 m	99.8%	99.6%	97.3%	**48%**
URA = 2.4 m URE = 1.2 m Bias = .5 m	**94.1%**	**76%**	**44.2%**	**0%**

ARAIM Results for 30 SVs & URA = .5 m



ARAIM currently predicated upon a user update rate of ~ 1hour

Are We Done?
Functional Hazard Analysis

Minor 10^{-3}	Slight increase in crew workload	
Major 10^{-5}	Significant increase in workload, Possible injury	Lateral navigation, Non-precision approach (RAIM)
Severe Major 10^{-7}	Unmanageable increase in workload, Possible fatality	Vertical guidance, LPV 200 (WAAS), Category I (LAAS)
Catastrophic 10^{-9}	Multiple fatalities, Loss of aircraft	Zero visibility, Category II & III (LAAS)

Conclusions

- Single frequency coverage is good within the countries fielding SBAS
- Dual frequency extends LPV coverage outside reference networks
- Expanding networks into southern hemisphere could allow global coverage of land masses
- ARAIM Potential for Multi-Constellation GNSS

Questions