Coverage Improvement for Dual Frequency SBAS

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Purpose

- GPS is adding a 2nd civil frequency in a protected aeronautical band
- WAAS and EGNOS already have plans to utilize new frequency
- India and Russia are developing their own SBAS systems
- Other regions have expressed interest in providing SBAS service
- Look ahead to possible future global coverage

Dual Frequency

- Two civil frequencies in the ARNS bands allow aircraft to directly estimate and remove ionospheric delays from their position estimates
  - *Removes the single largest source of uncertainty affecting today's GNSS*

- Most significant remaining threats are satellite failure based
  - *Design a new VPL equation targeting single satellite faults*

Single SV Fault VPL

- Single frequency VPL well suited for faults affecting multiple ranges
  - *(e.g. ionospheric threats)*
- Dual frequency VPL can leverage small probability of satellite fault
  - *While one SV may be faulted, others are expected to be nominal*
  - *Still need term for rare nominal and tropospheric threats*
- Also include terms for nominal biases

Nominal Biases

- Several error sources have been identified as creating potential bias terms for users
  - *Errors that will affect the user's range in a consistent manner*
    - Nominal signal deformations
    - Antenna group delay biases
- Bias terms also allow for bounding of non-Gaussian behavior[1]

1 Rife, et al. "Paired Overbounding and Application to GPS Augmentation," IEEE PLANS 2004

Dual Frequency VPL

$$VPL_{H_0} = K_{HMI}\sqrt{\sum_{i=1}^{N} s_{3,i}^2 \sigma_{ff,i}^2} + \sum_{i=1}^{N} \left| s_{3,i} bias_{nom,i} \right|$$

$$VPL_{H_1} = K_{fault}\sqrt{\sum_{i=1}^{N} s_{3,i}^2 \sigma_{ff,i}^2} + \sum_{i=1}^{N} \left| s_{3,i} bias_{nom,i} \right| + \max_i \left| s_{3,i} bias_{fault,i} \right|$$

$$VPL = \max\left[VPL_{H_0}, VPL_{H_1} \right]$$

$$\sigma_{ff,i}^2 = \sigma_{SV\_ff,i}^2 + \sigma_{trop,i}^2 + \sigma_{DF\_air,i}^2$$

$$\sigma_{DF\_air,i}^2 = \left(\frac{f_1^2}{f_1^2 - f_5^2} \right)^2 \cdot \sigma_{L1,i}^2 + \left(\frac{f_5^2}{f_1^2 - f_5^2} \right) \cdot \sigma_{L5,i}^2$$

Simulation Setup

- Stanford's SBAS availability tool, MAAST[2], used to simulate SBAS
- 28 GPS satellite using almanac from April 8, 2009
  - *removed PRNs 1, 5, 25,& 32*
- Worldwide 5 degree x 5 degree grid
- 300 sec time steps for 1 sidereal day
- Only WAAS Geos provide ranging

2 Jan, et al., "Matlab Simulation Toolset for SBAS Availability Analysis," *ION GPS-2001*

Numerical Values

- σ_{ff} set to $\sigma_{flt}/3$ (includes $\delta UDRE$ term from MT28)
- σ_{trop} as in DO-229D WAAS MOPS
- σ_{L1} (= σ_{L5}) as in WAAS MOPS
- K_{HMI} = 5.33
- $bias_{nom}$ = 0.5 m
- K_{fault} = 2.33
- $bias_{fault}$ = 5.33 x σ_{flt}

Caveats

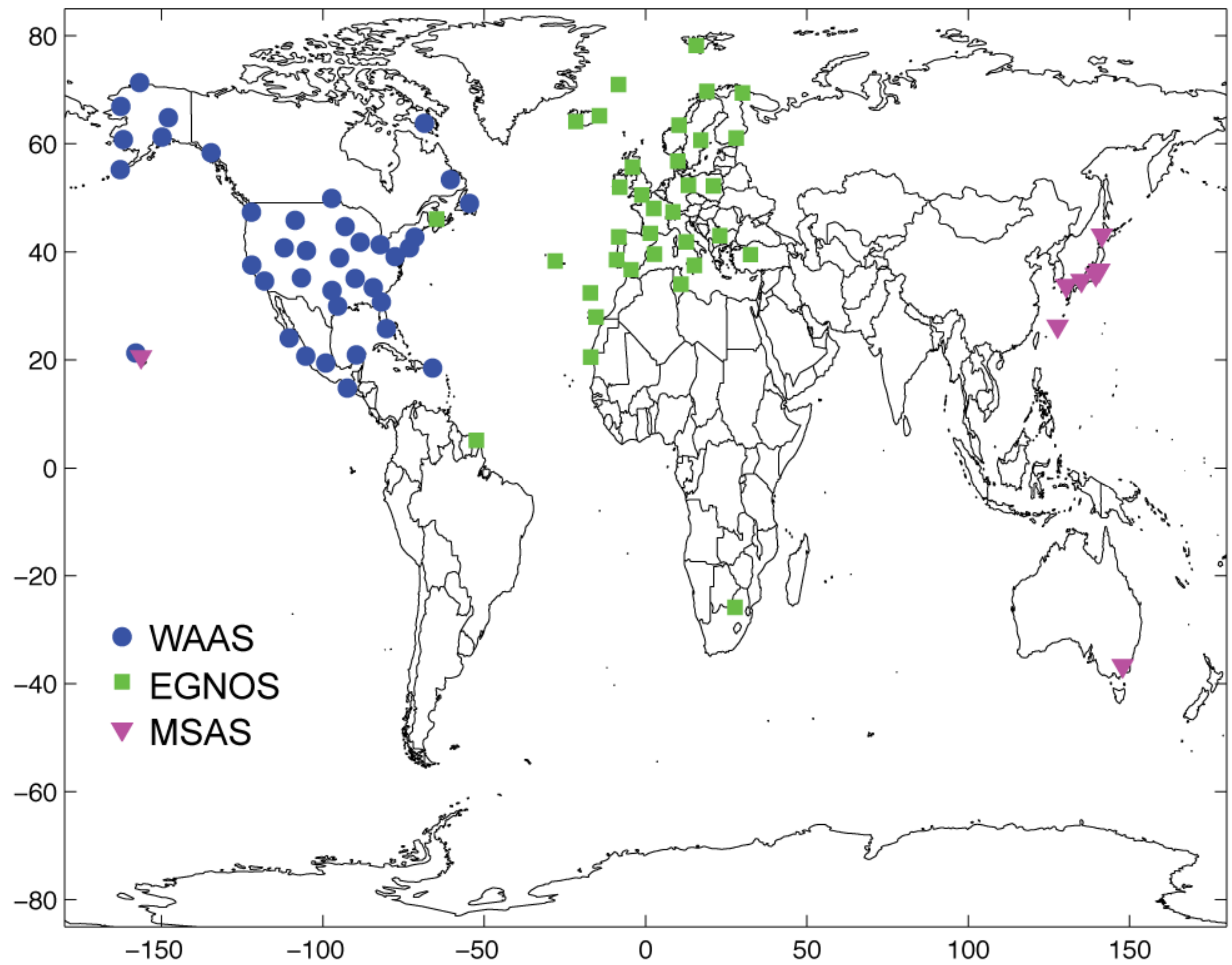
- New and updated reference networks are subject to change
- MAAST simulates WAAS algorithms and is not as representative of the other SBASs
- Expansions into the southern hemisphere are speculative on the authors part
- Coverage plots do not represent official commitment

Current Reference Networks

WAAS

EGNOS

MSAS

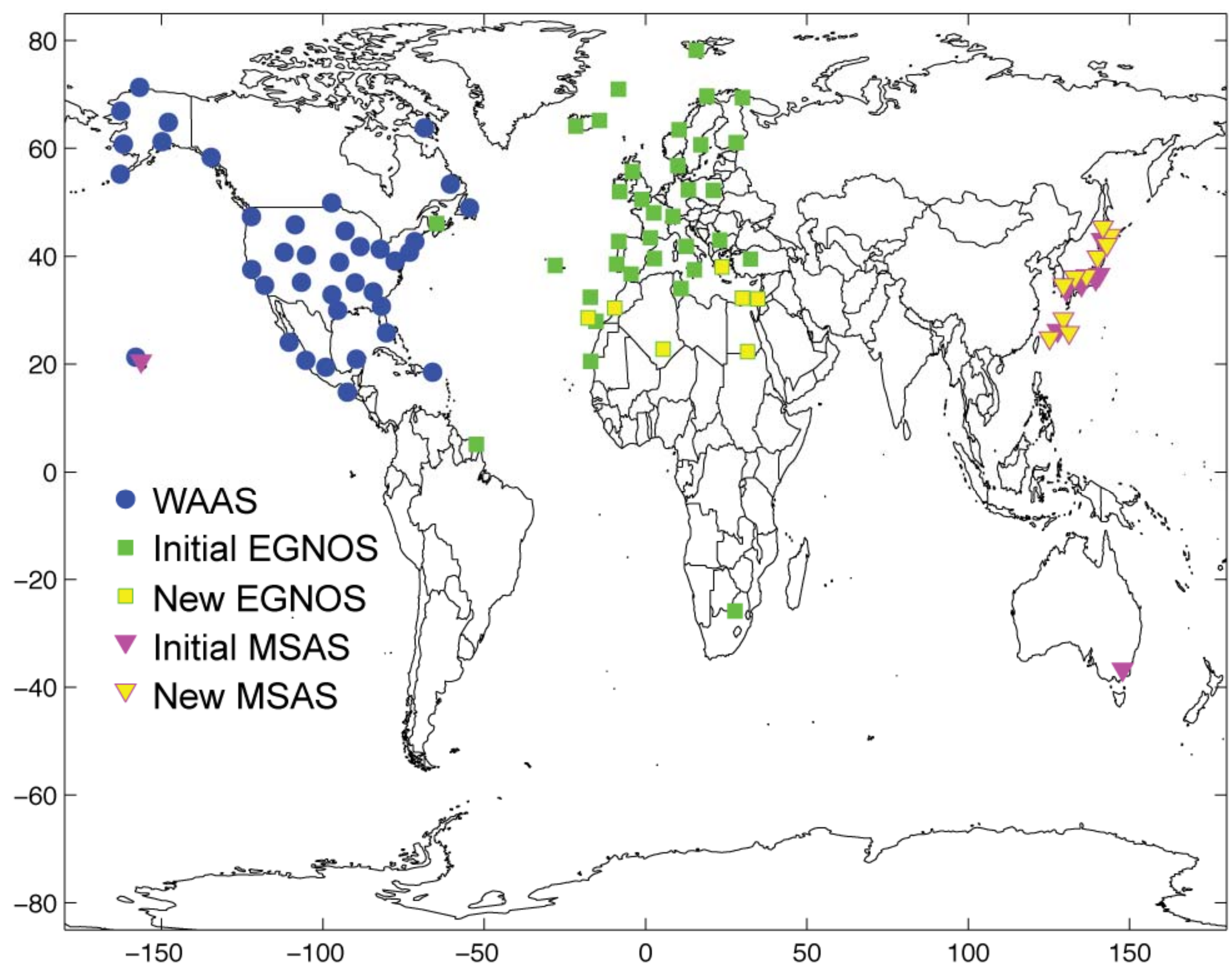


Improved Reference Networks

WAAS

EGNOS

MSAS



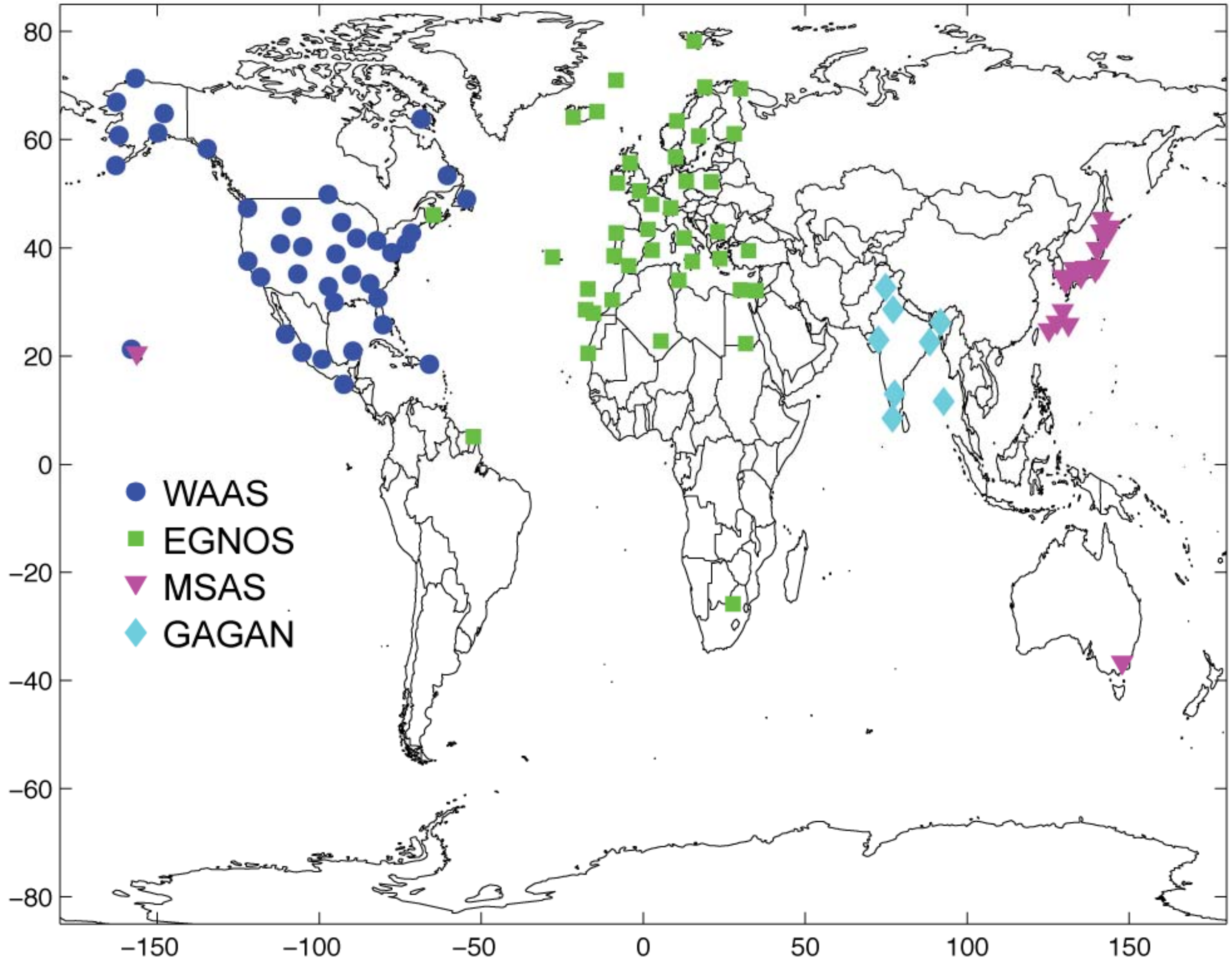
Reference Networks with GAGAN

WAAS

EGNOS

MSAS

GAGAN



Reference Networks with GAGAN and SDCM

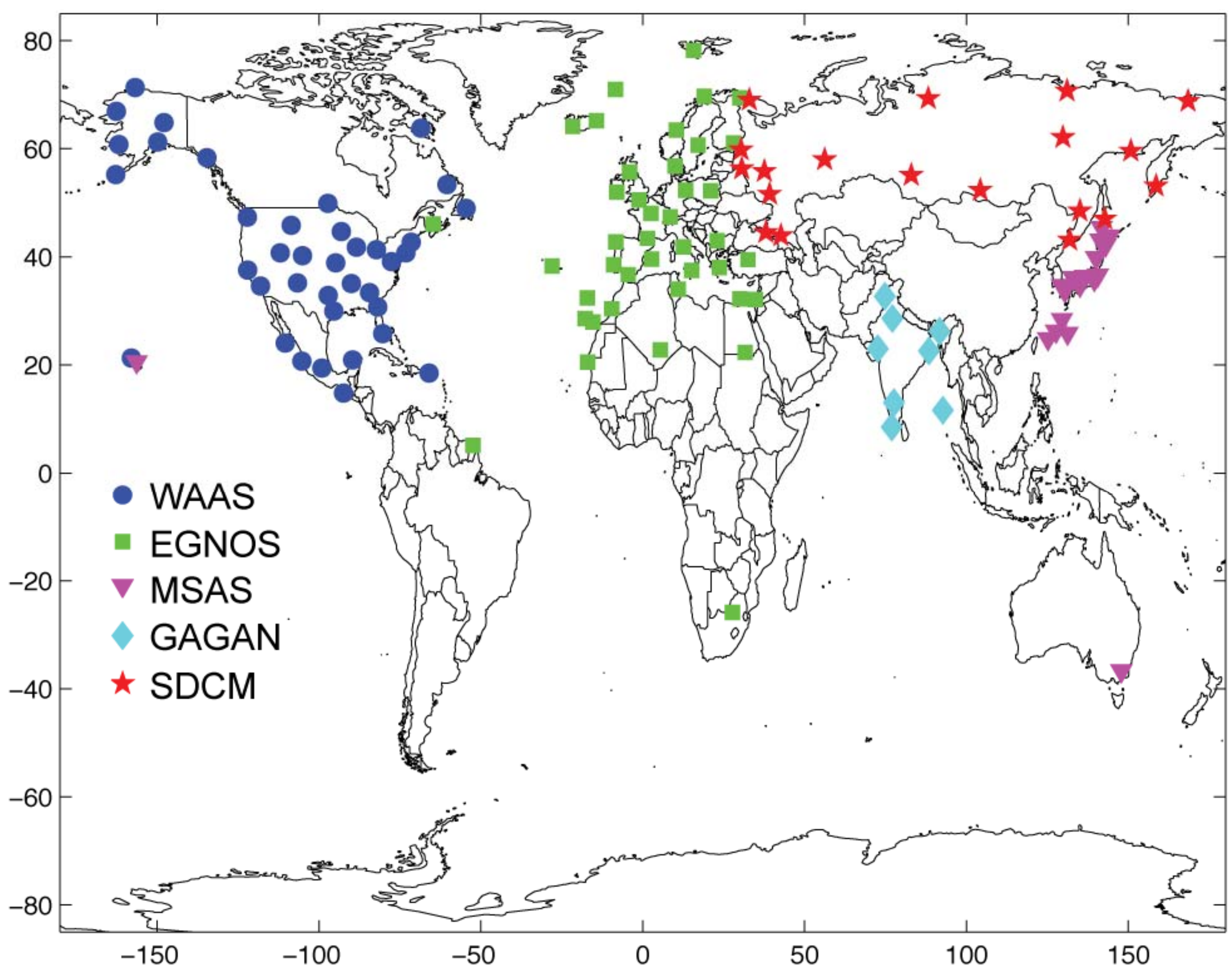
WAAS

EGNOS

MSAS

GAGAN

SDCM

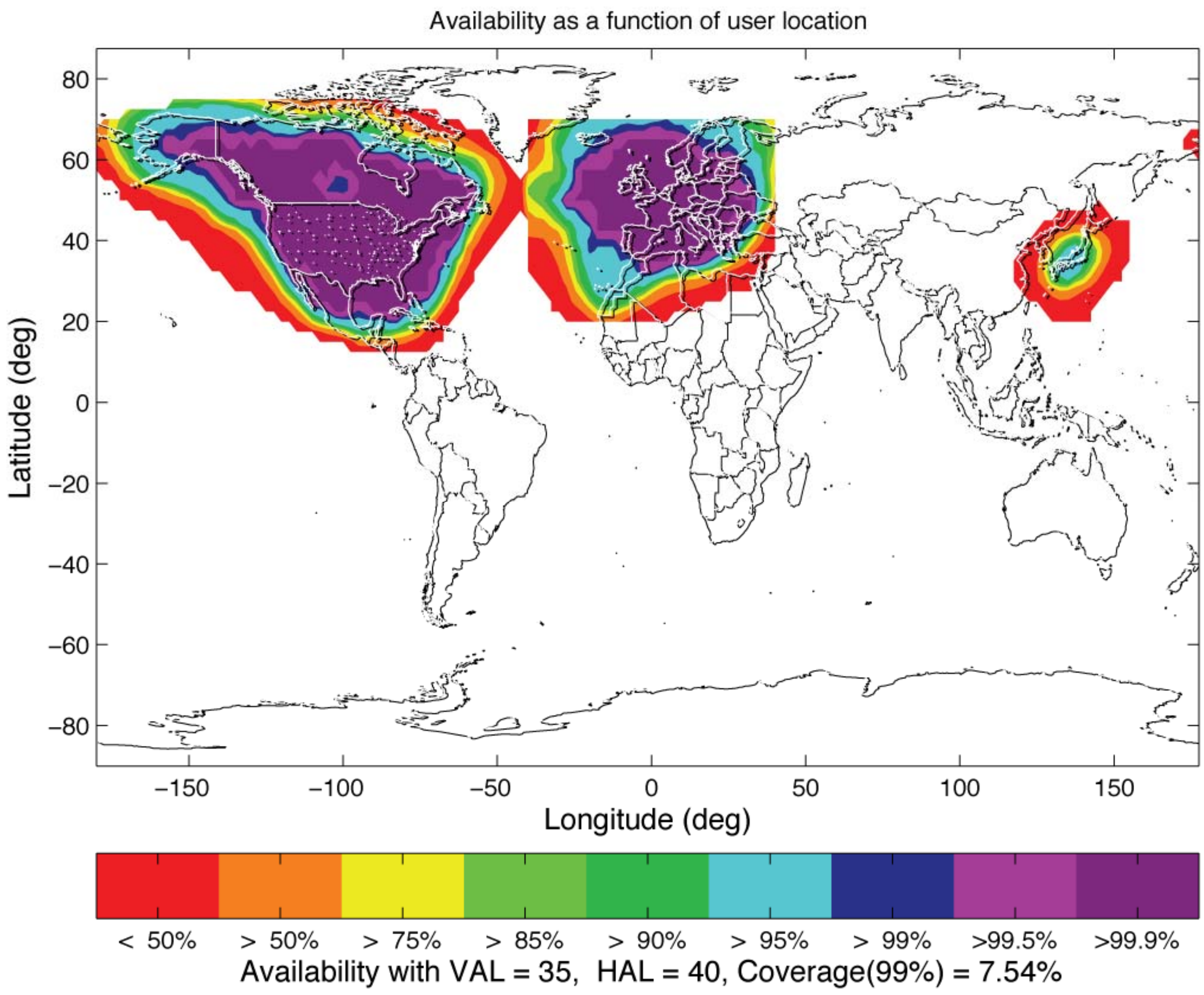


Current Coverage

WAAS

EGNOS

MSAS

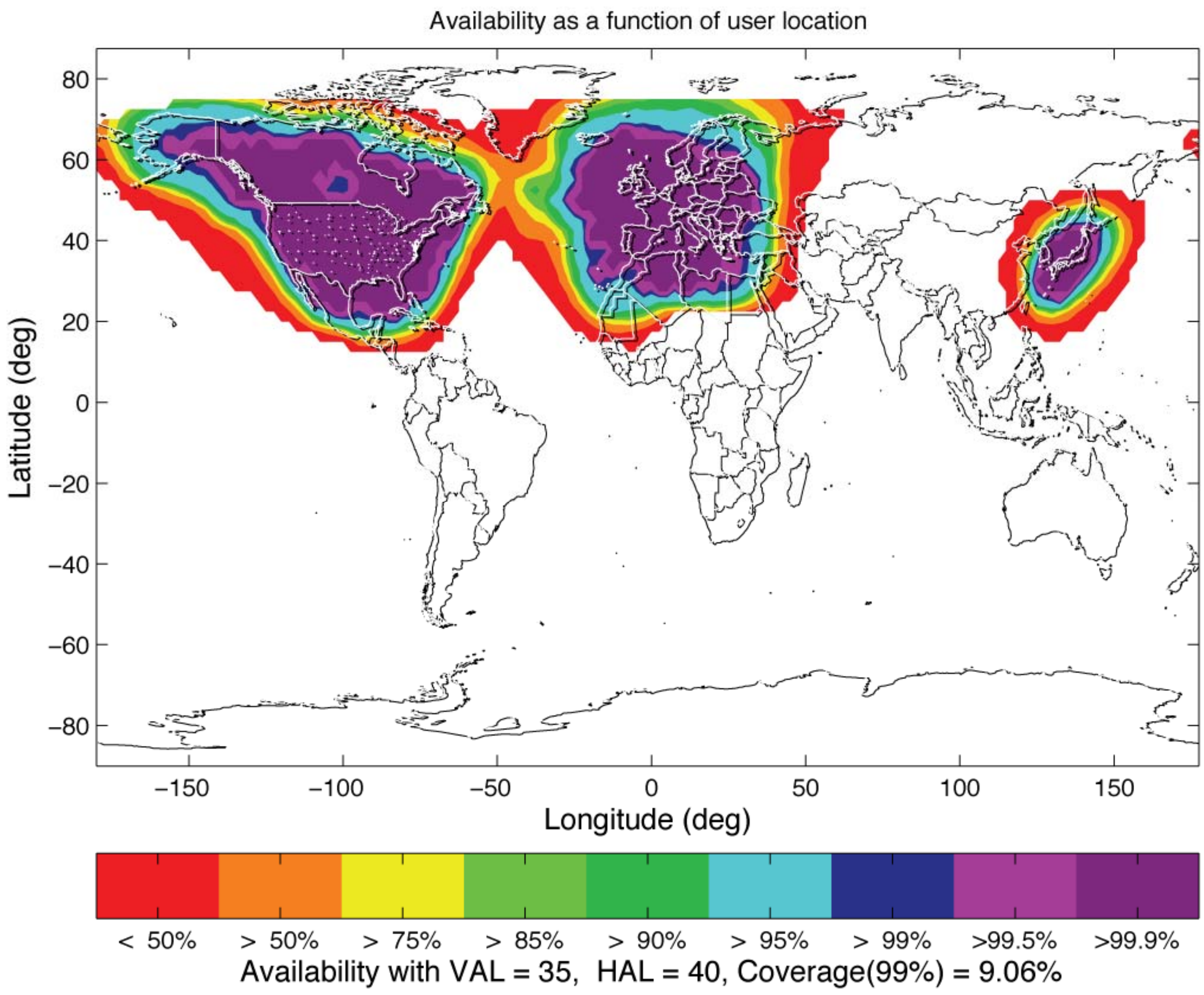


Improved Single Frequency Coverage

WAAS

EGNOS

MSAS

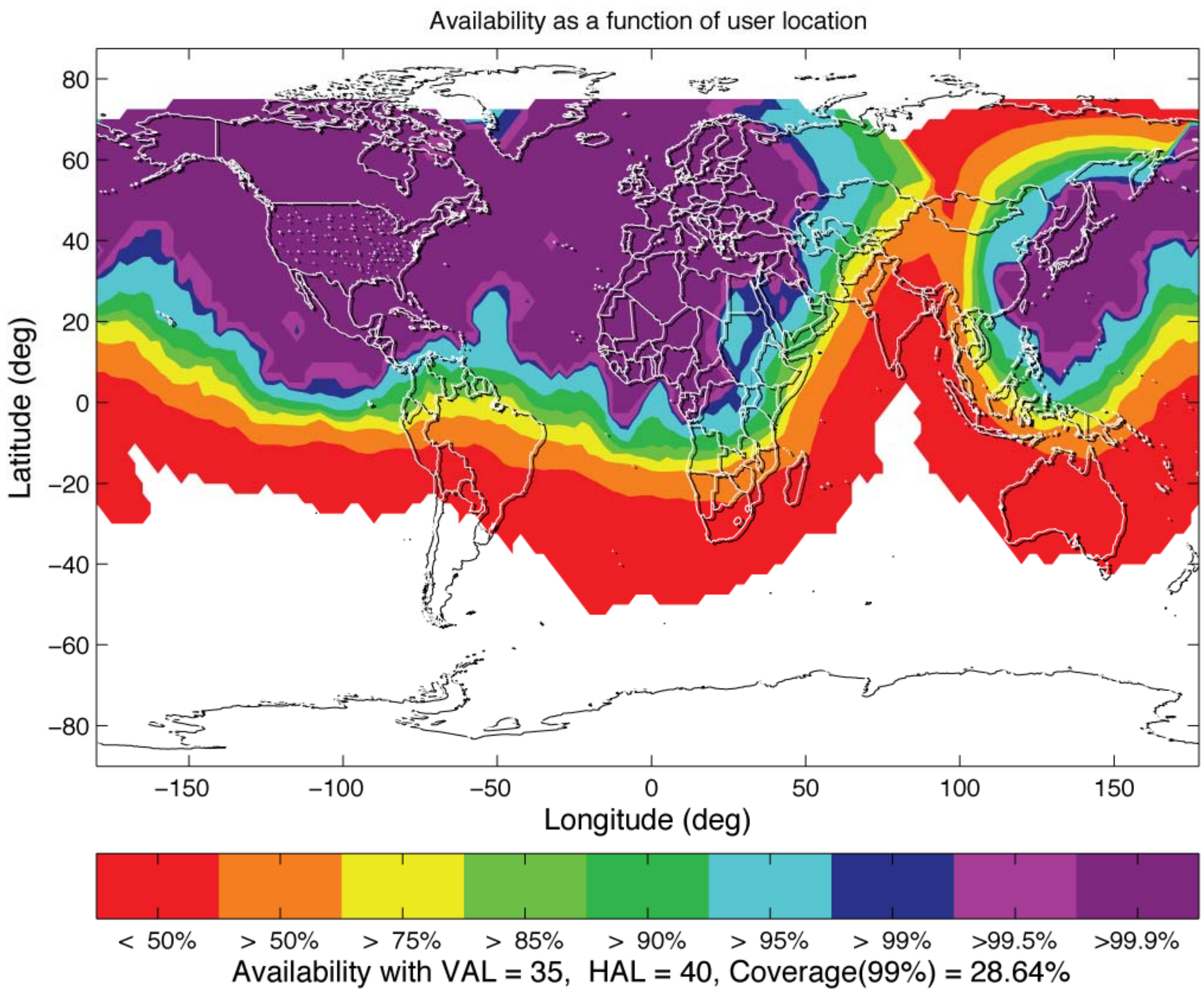


Dual Frequency Coverage (WAAS, EGNOS, MSAS)

WAAS

EGNOS

MSAS



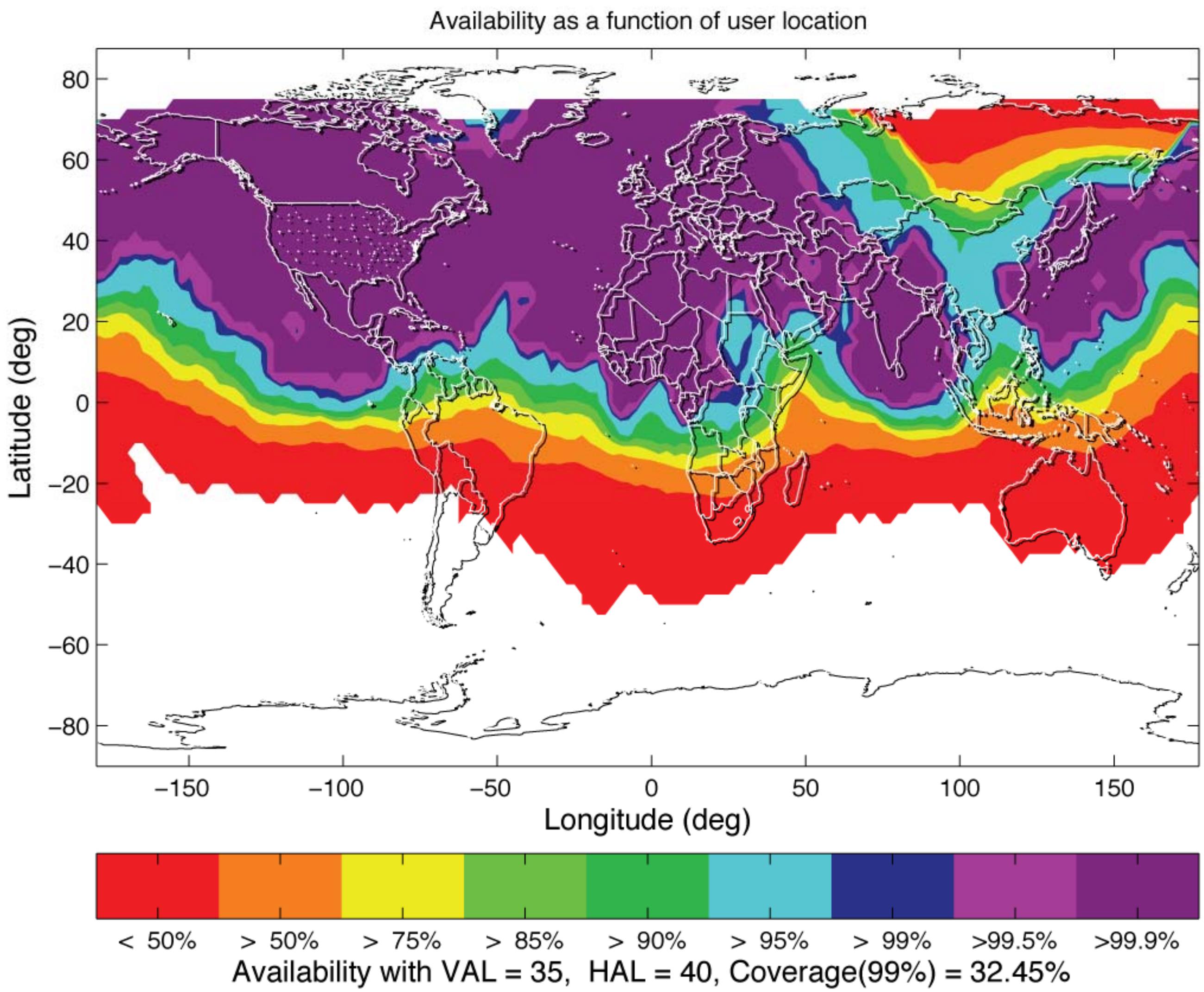
Dual Frequency Coverage (with GAGAN)

WAAS

EGNOS

MSAS

GAGAN



Dual Frequency Coverage (with GAGAN + Russia)

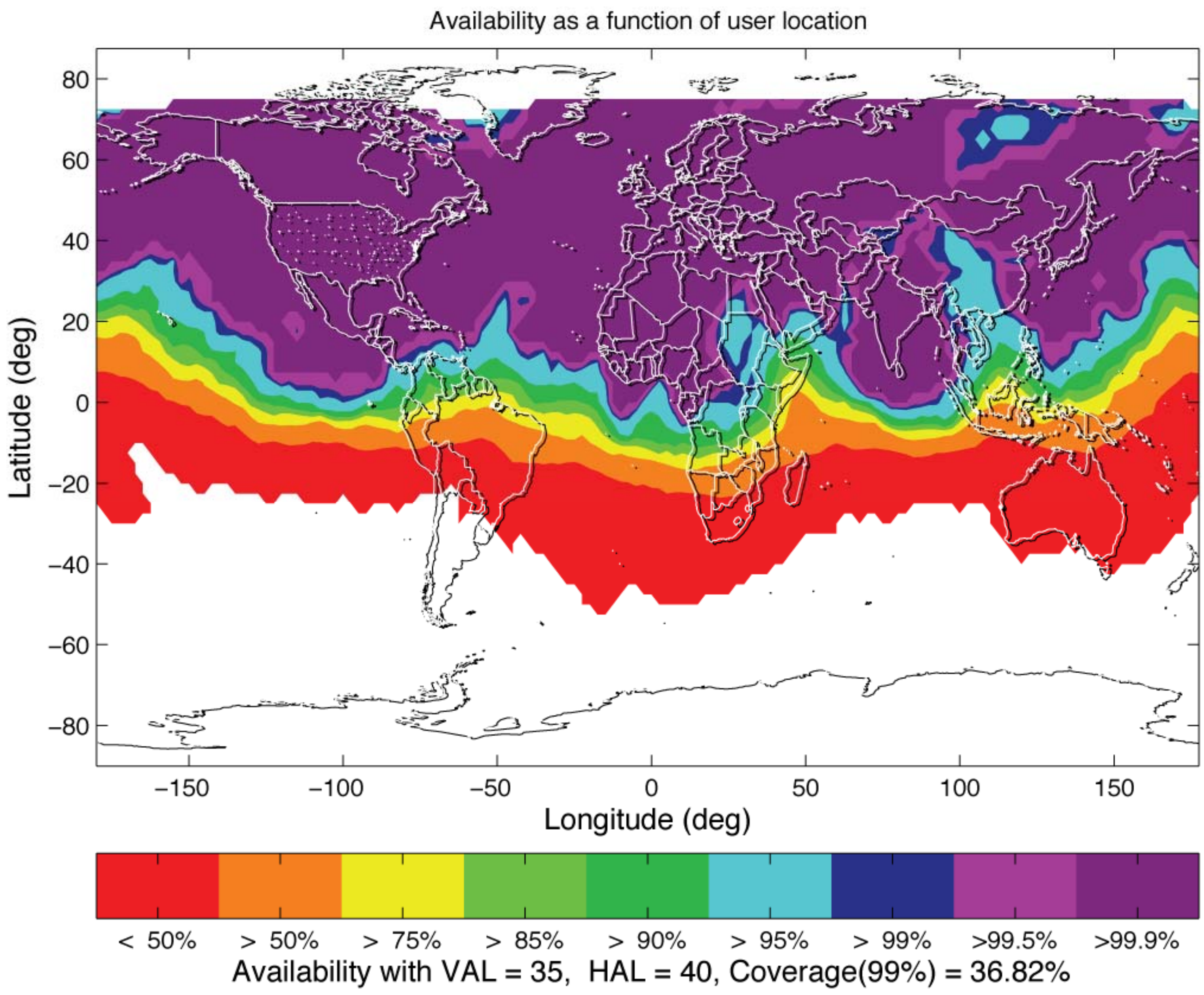
WAAS

EGNOS

MSAS

GAGAN

SDCM



Expanded Networks

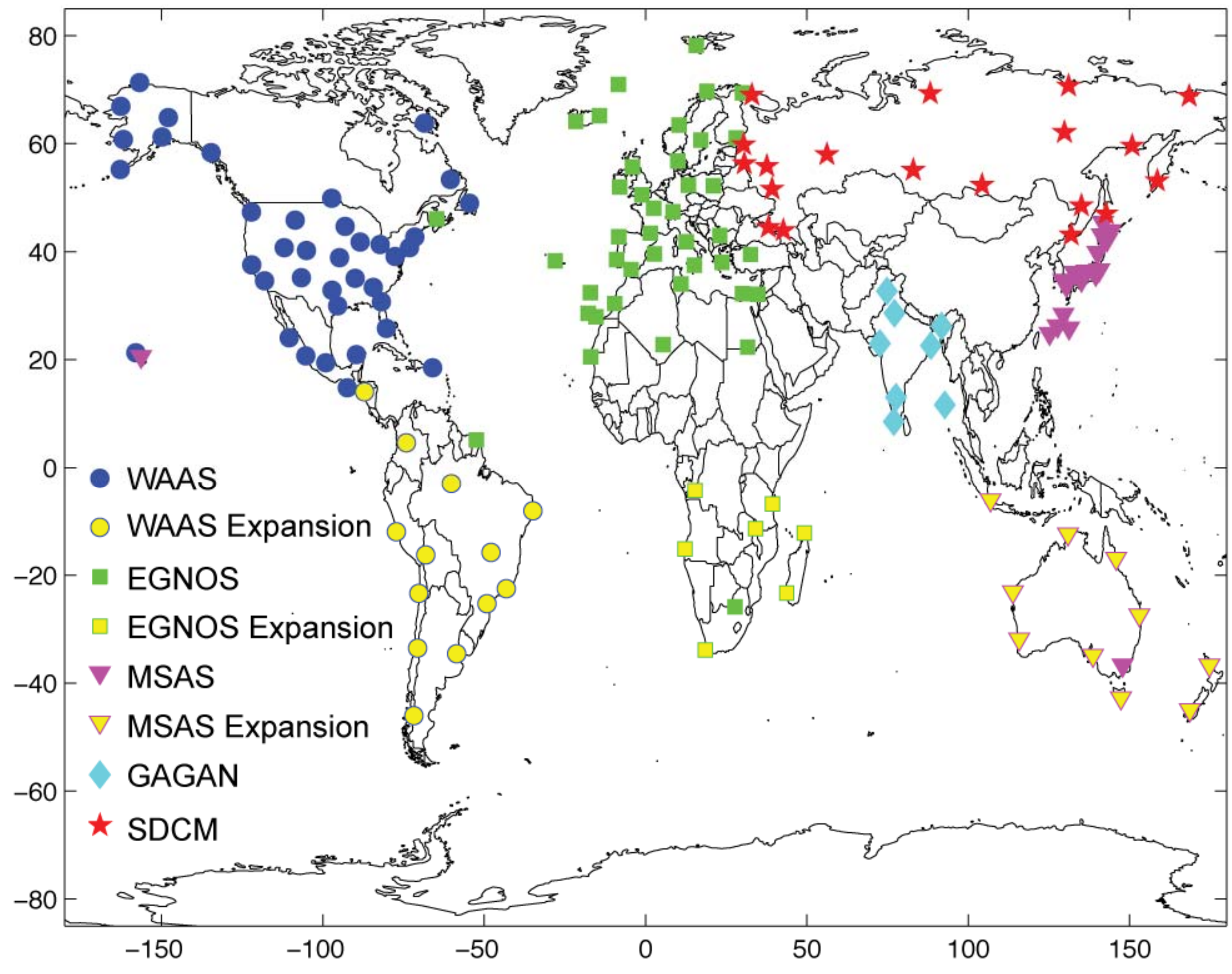
WAAS

EGNOS

MSAS

GAGAN

SDCM



Dual Frequency, Expanded Networks

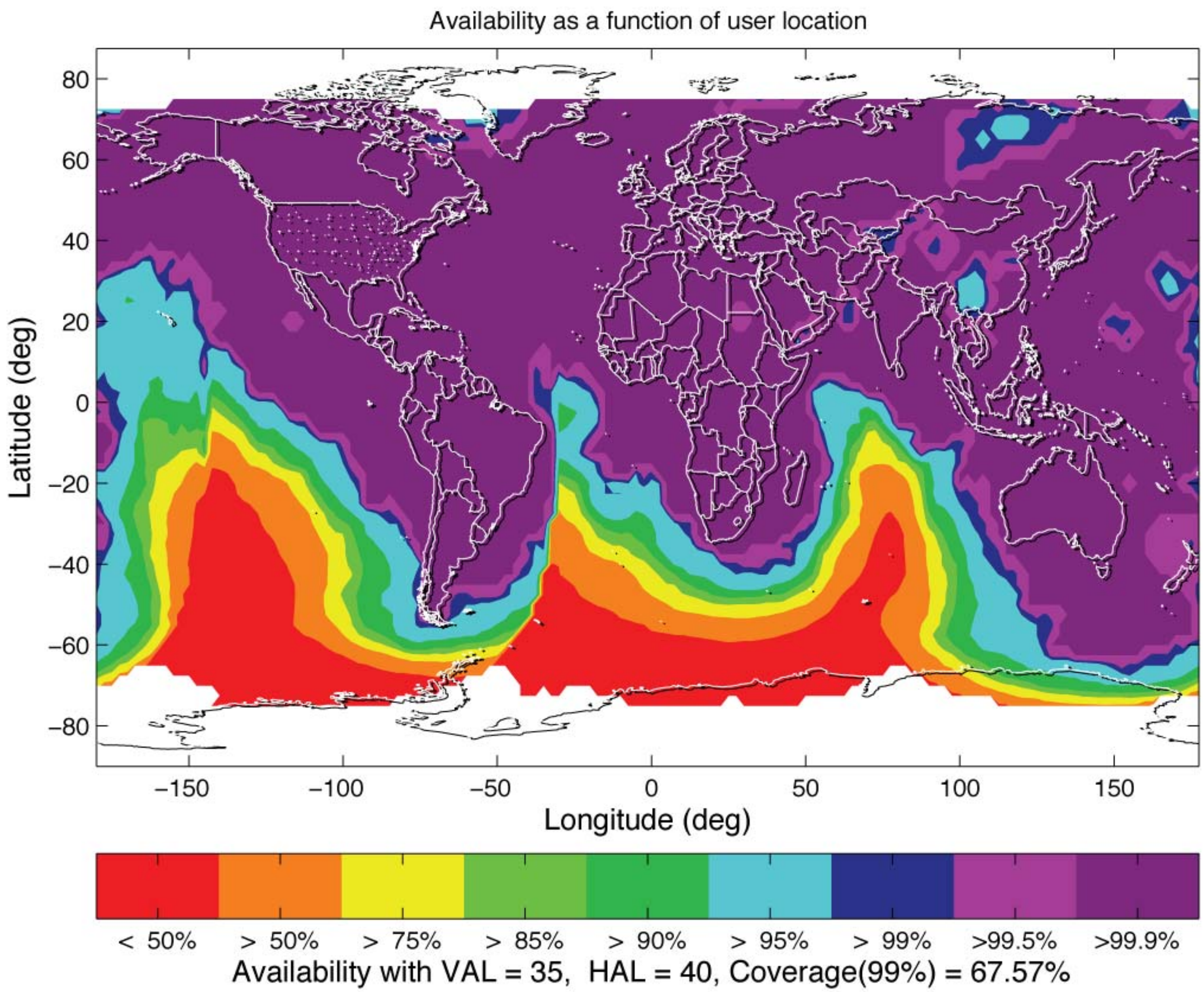
WAAS

EGNOS

MSAS

GAGAN

SDCM



Dual Frequency + Second Constellation (Galileo)

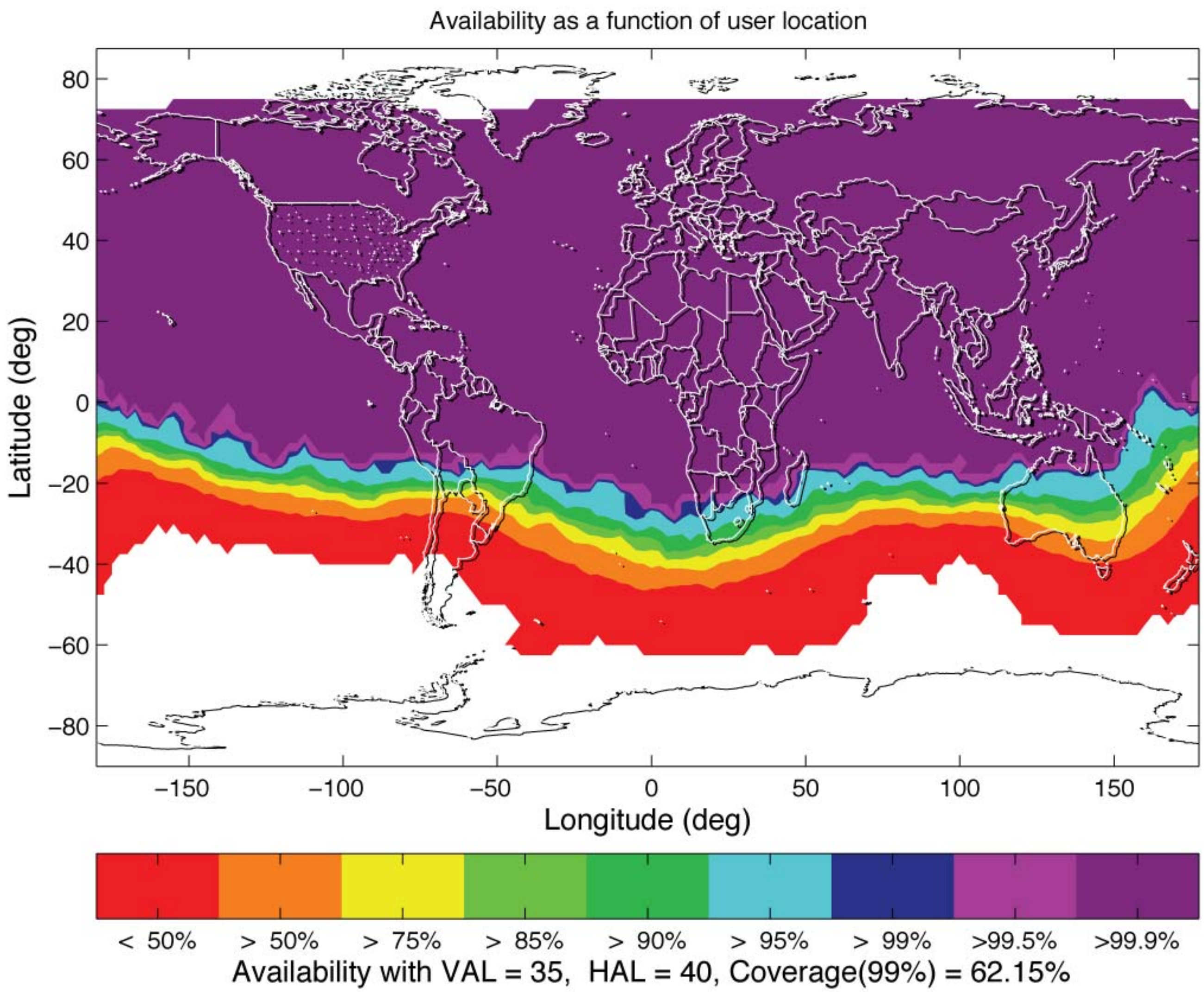
WAAS

EGNOS

MSAS

GAGAN

SDCM



Dual Frequency, Dual GNSS, Expanded Networks

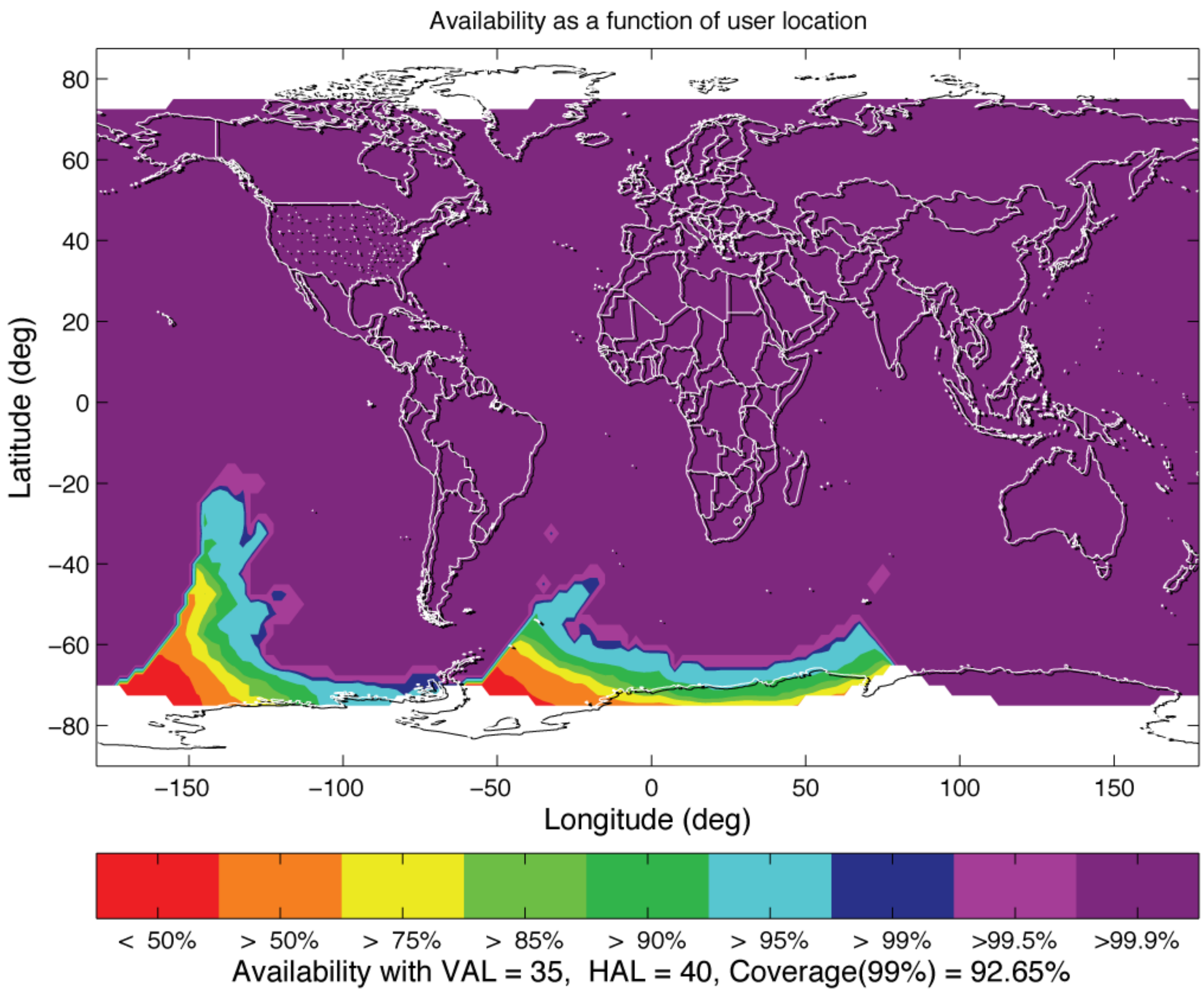
WAAS

EGNOS

MSAS

GAGAN

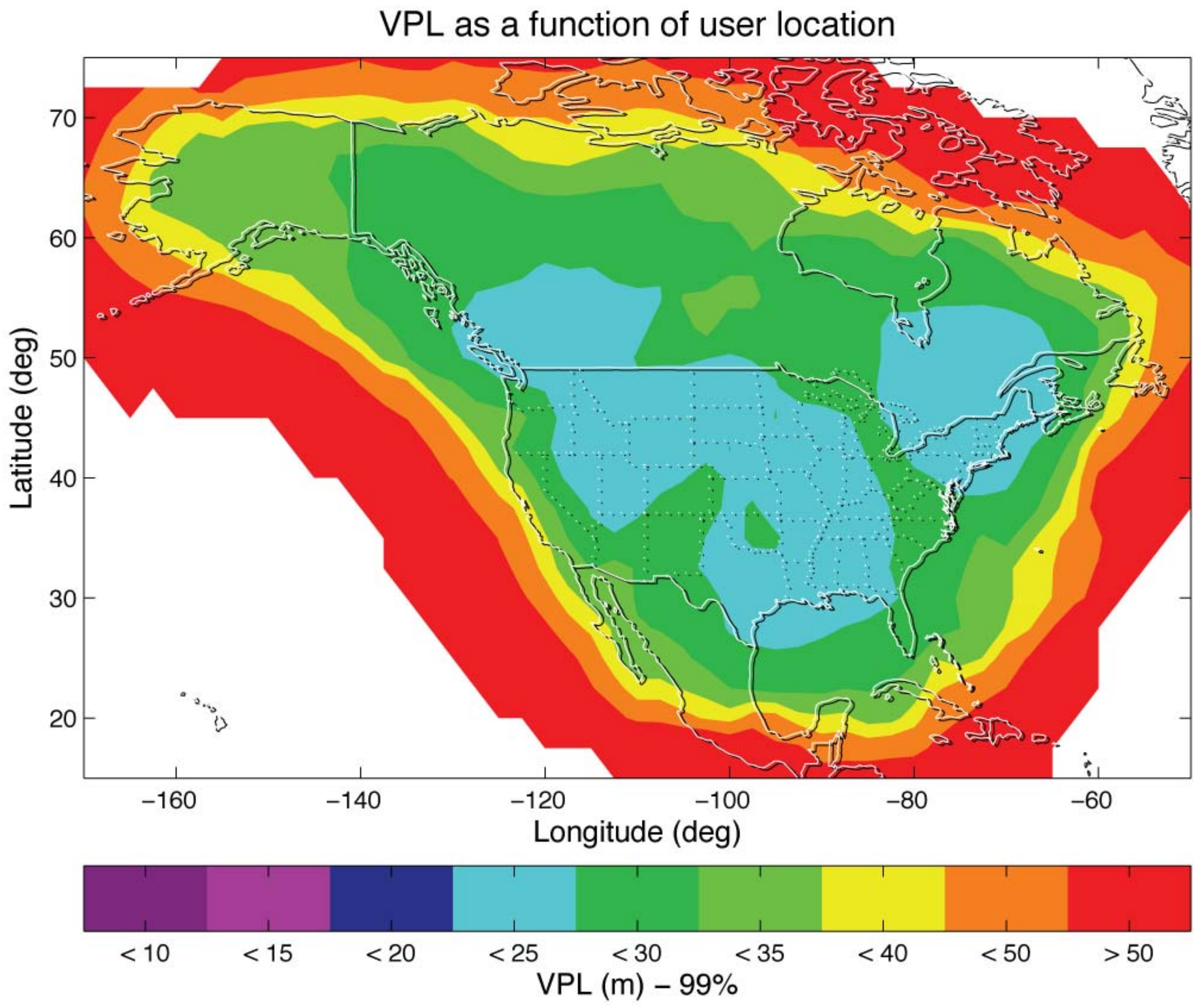
SDCM



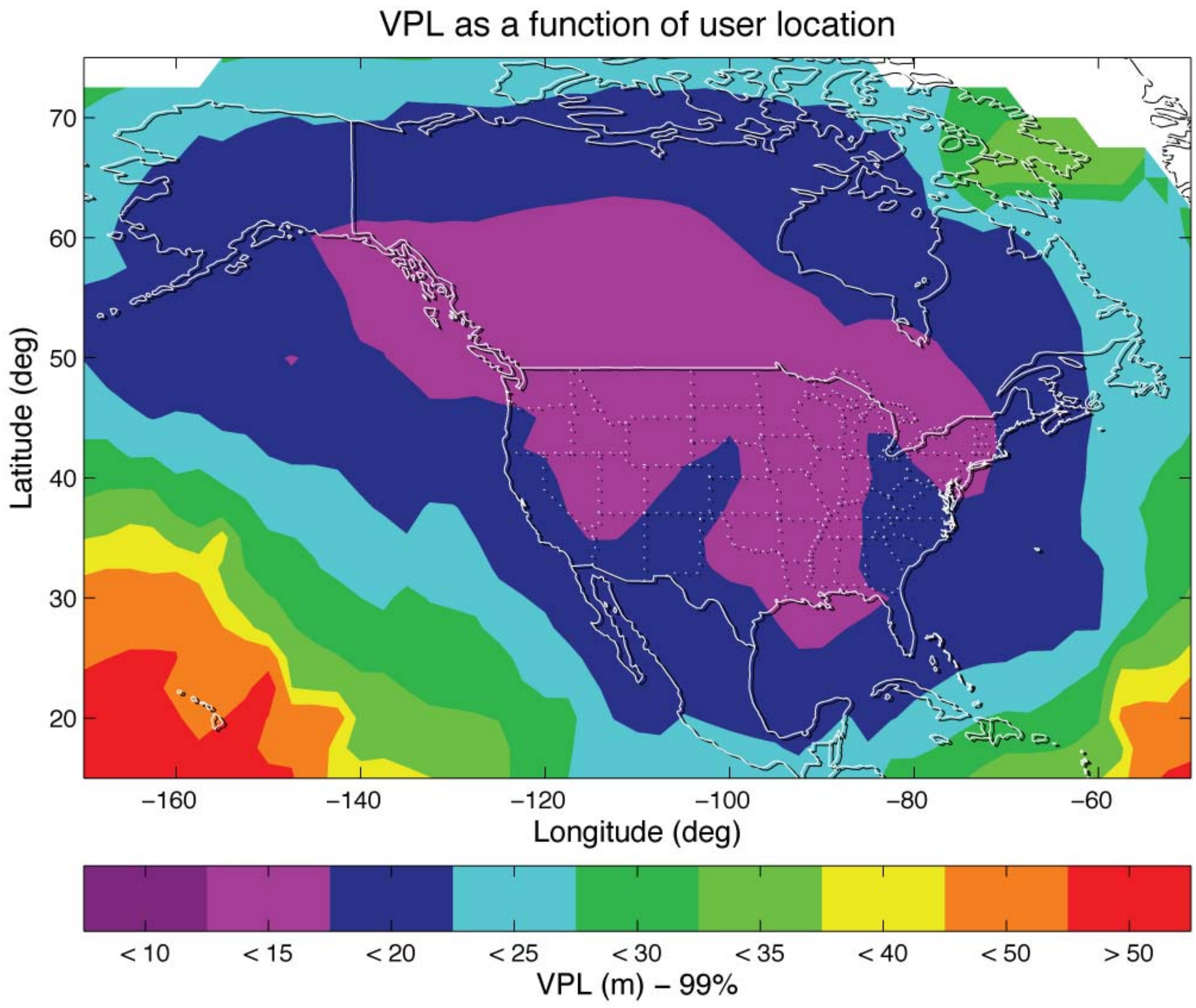
Conclusions

- Single frequency coverage is good within the countries fielding SBAS
- Dual frequency extends coverage outside reference networks & allows LPV operation in equatorial areas
- Expanding networks into southern hemisphere could allow global coverage of land masses
- Additional constellations allow even greater coverage with fewer stations

WAAS Single Frequency 99% VPL



WAAS Dual Frequency 99% VPL



WAAS Dual Frequency, Dual GNSS 99% VPL