Extending Wide Area Augmentation System Service into Central and South America

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Overview

- **WAAS Components (generic)**
  - **Space-based**
  - **Ground-based**
  - **User-equipment/Avionics**

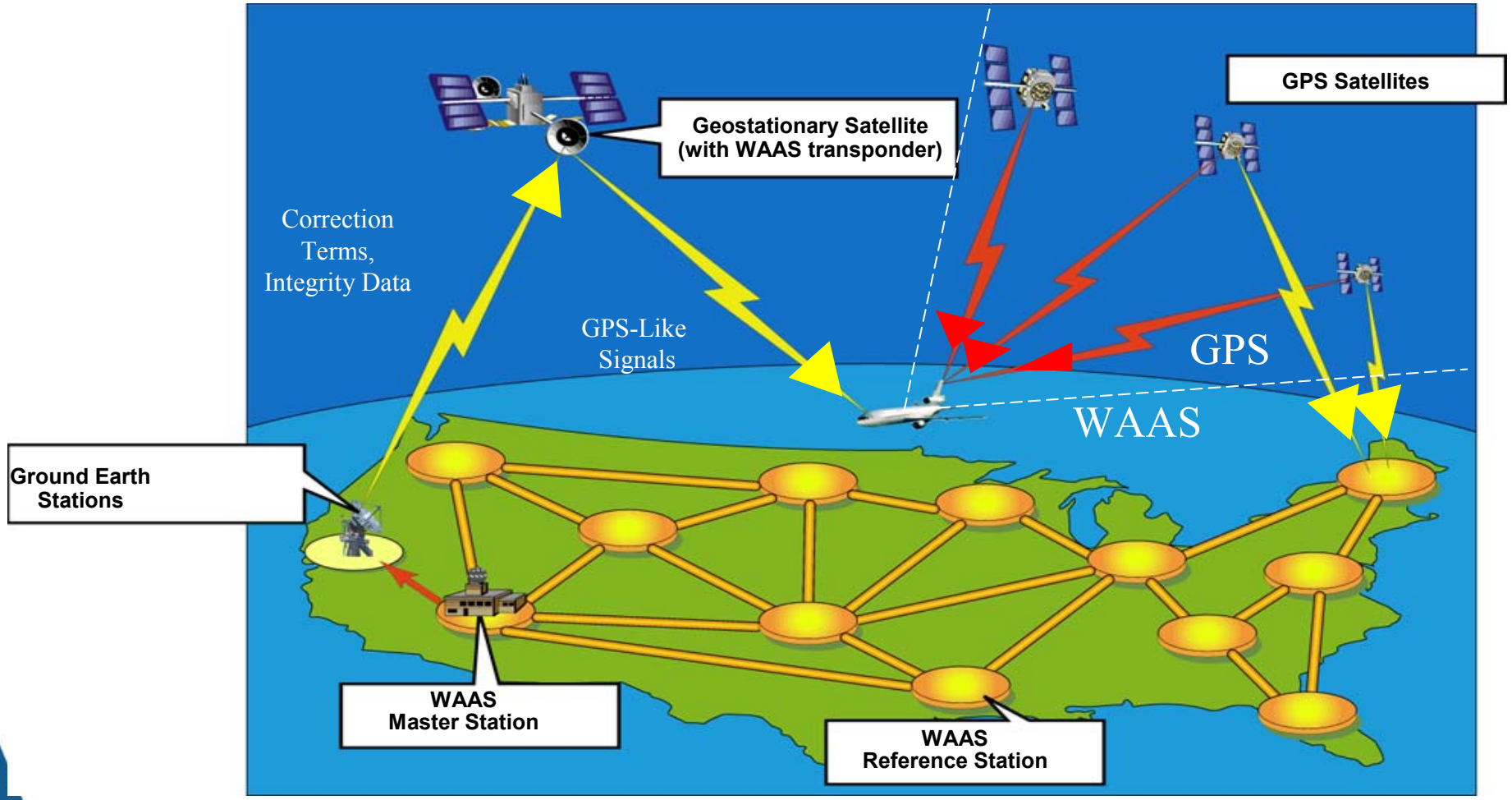
- **WAAS Service Availability**
  - **Initial Operational Capability (IOC) in North America**
  - **Full Operational Capability (FOC)**
  - **Beyond FOC: Central and South America**

Overview (concluded)

- SWAT
  - Background
  - Modeling Capabilities
  - Limitations
  - "Availability of Service"
- WAAS Analysis of Central and South America
  - Assumptions
  - Identify cases
  - Analysis results
- Conclusion
  - Review results
  - Future investigations/recommendations
  - Closing

WAAS Components

Wide Area Augmentation System (generic)



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WAAS Service Availability

Analysis Specifications

- Analysis region
- Components (space-based & ground-based)
  - quantity, location
- Error models (algorithms and parameters)
- Reliability models (for space-based elements)
  - Stochastic
  - Deterministic
  - No Failures
- Service Criteria (examples):

Service Requirement	*Vertical Alert Limit*	*Horizontal Alert Limit*
LNAV/VNAV	50 meters	556 meters
LPV	**50 meters**	**40 meters**
GLS	12 meters	40 meters

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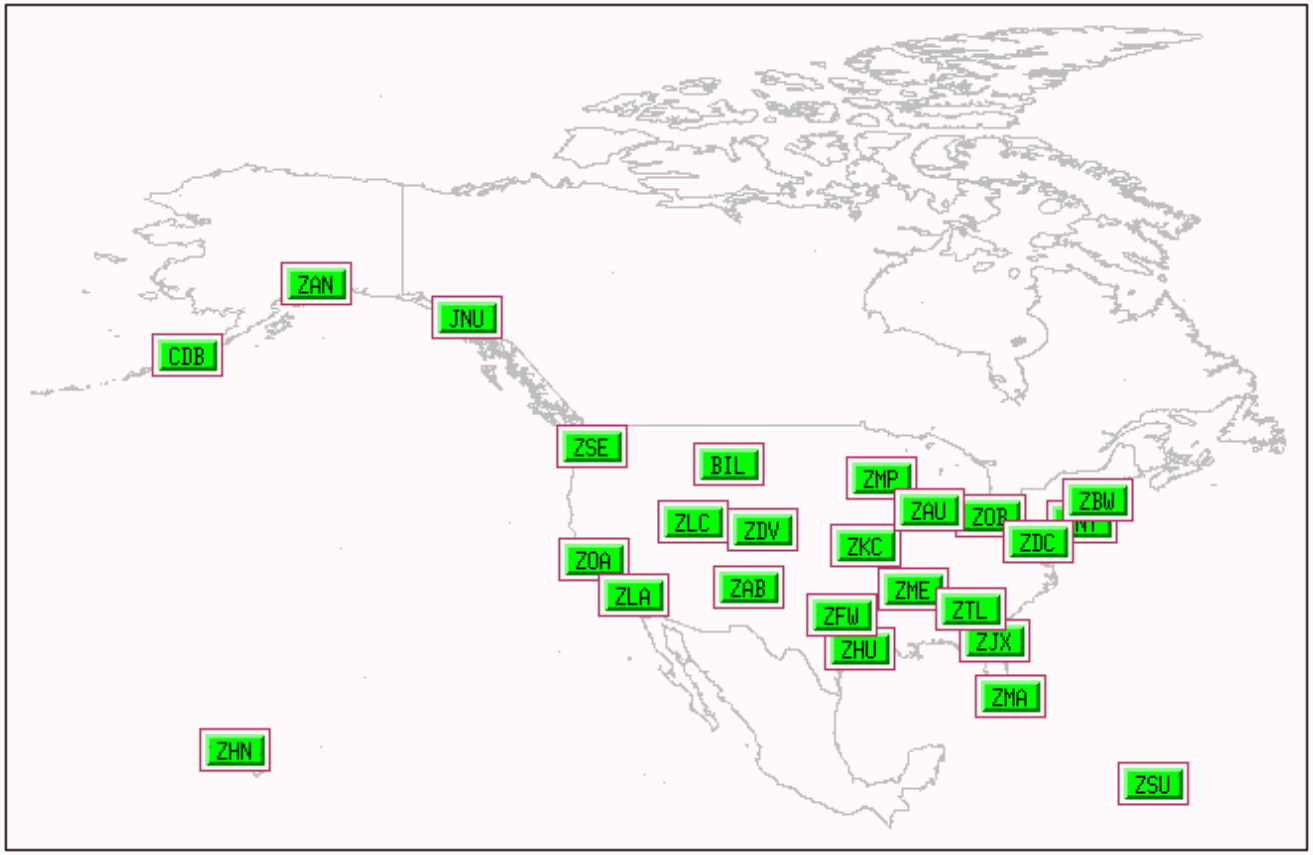
25 WAAS IOC Reference Stations



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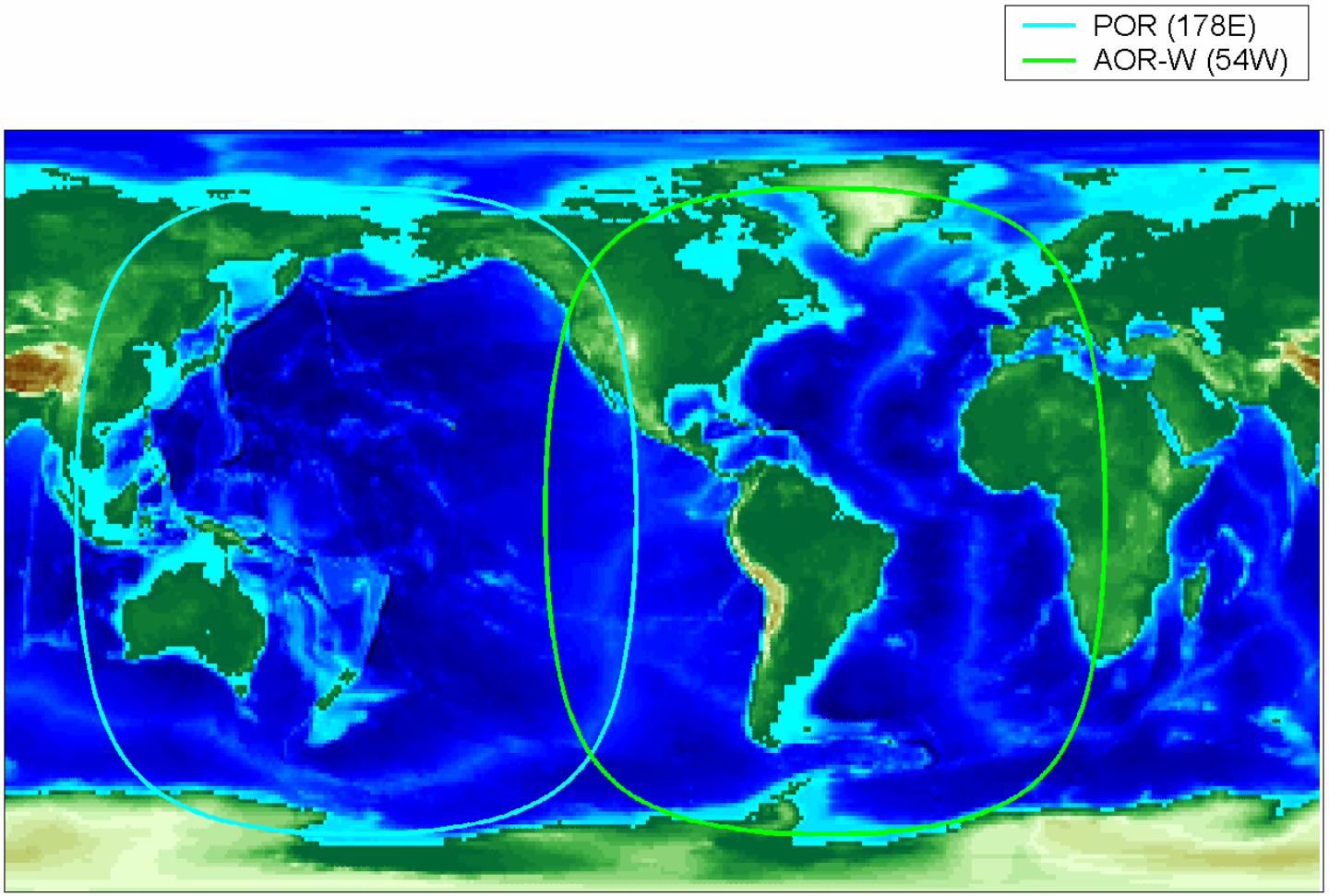
GEO Satellite Footprints for 178 E and 54 W



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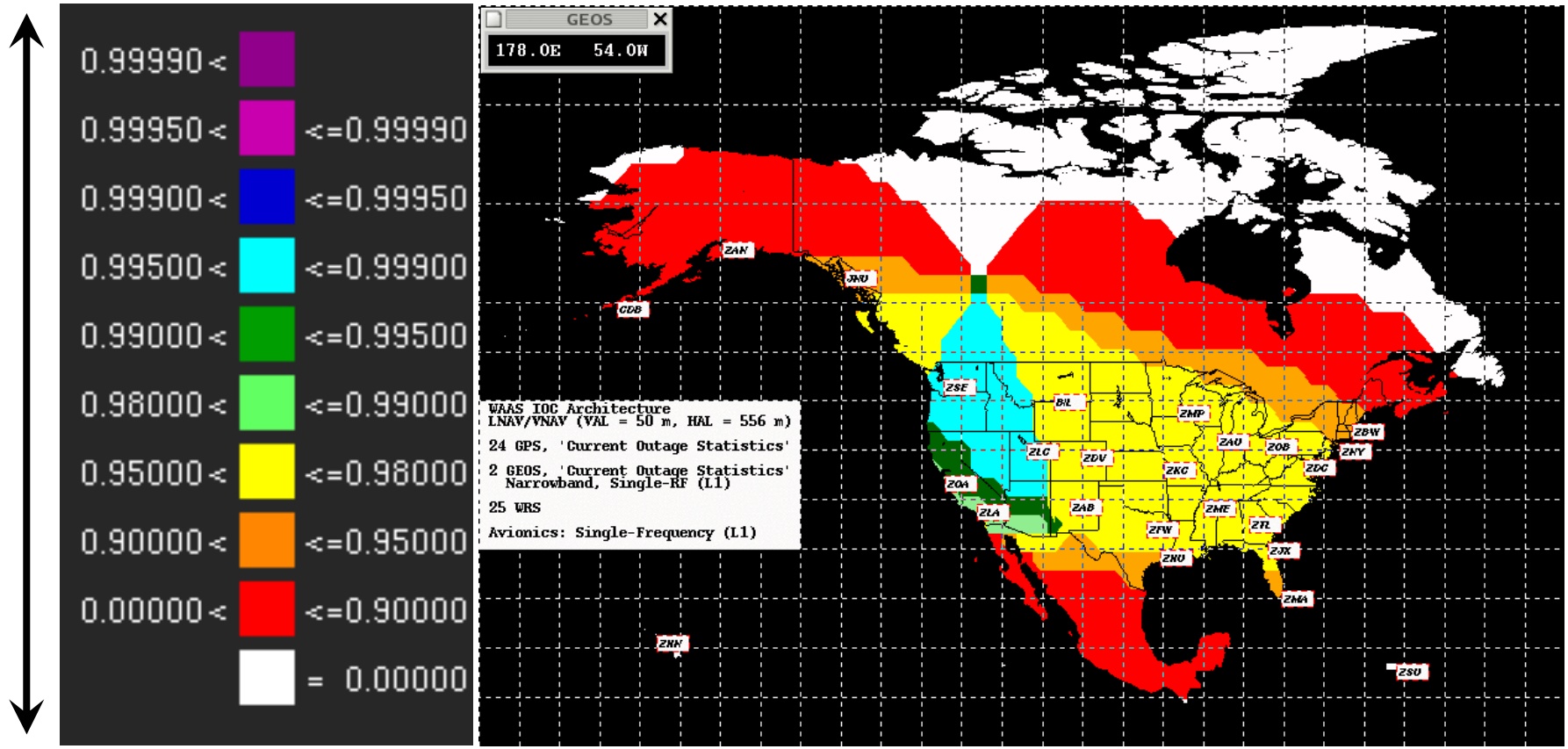
WAAS IOC
LPV service (VAL: 50 m, HAL: 40 m)

HIGHER AVAILABILITY

25 WRS, 24 GPS, 2 GEO (178 E, 54 W)



LOWER AVAILABILITY

24 hour average

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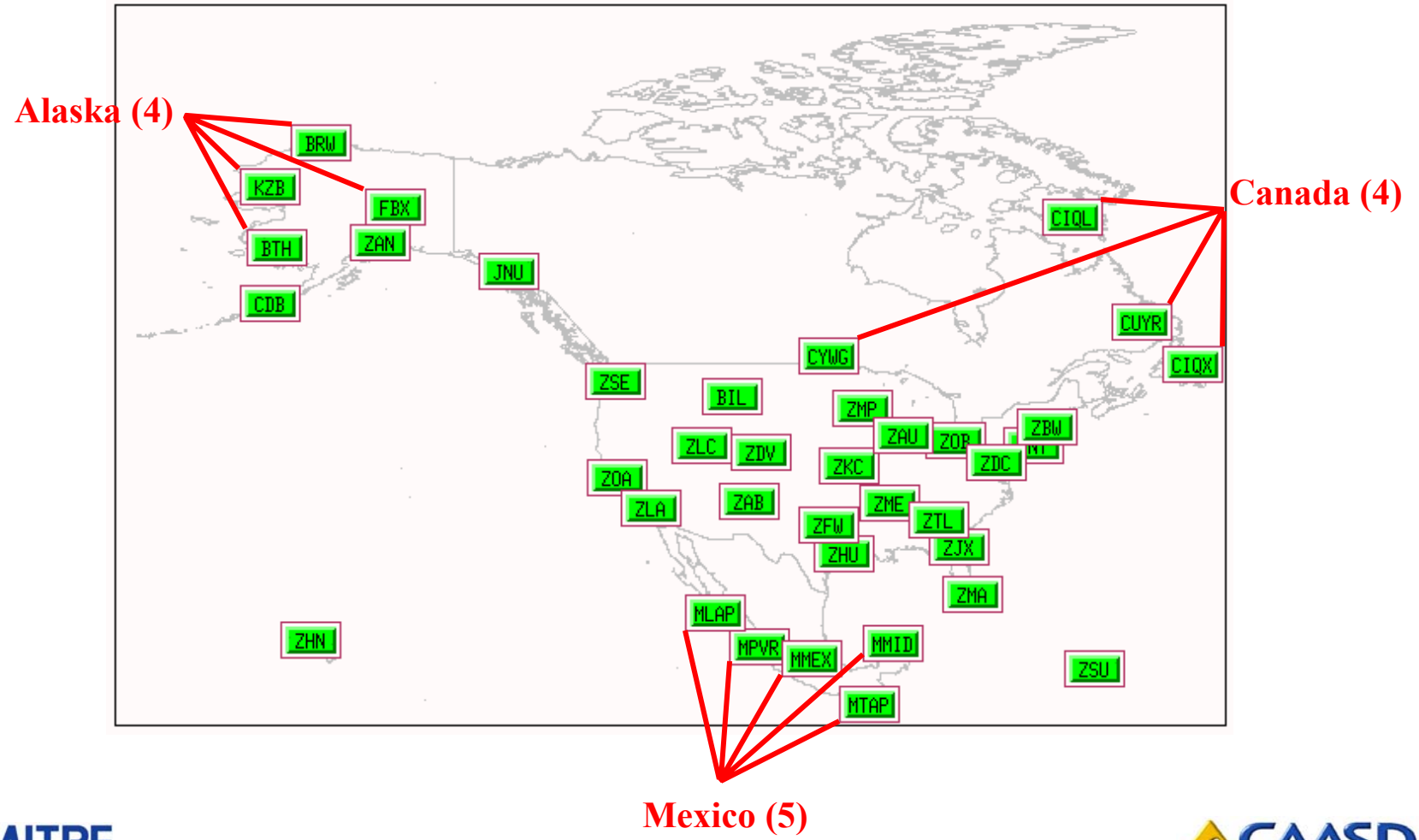
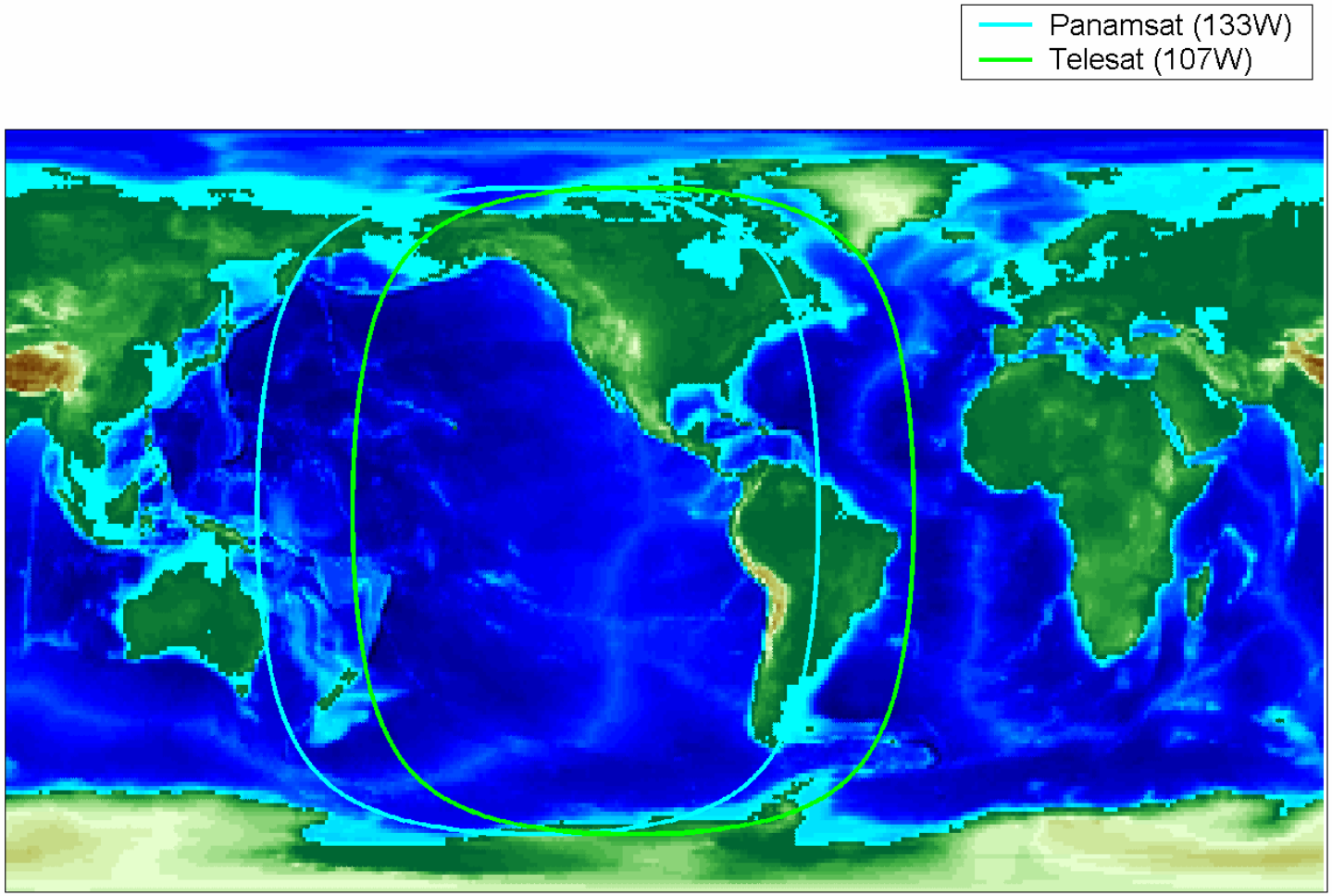
38 WAAS FOC Reference Stations



GEO Satellite Footprints for 133 W and 107 W



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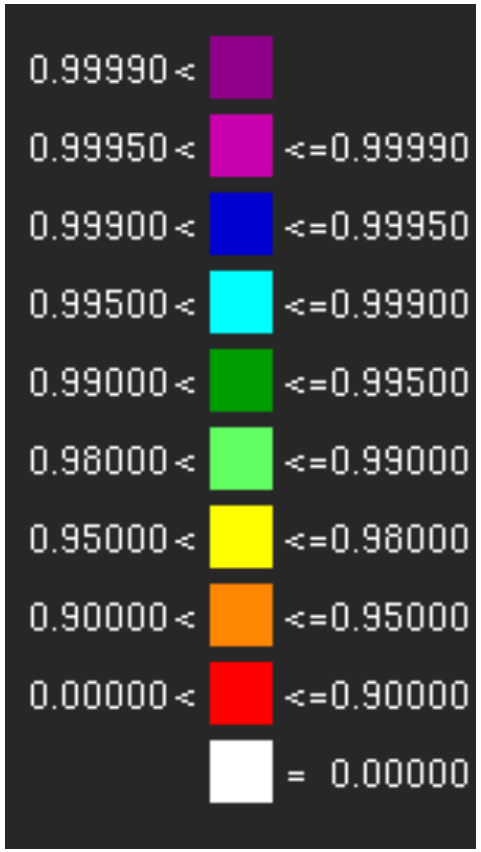
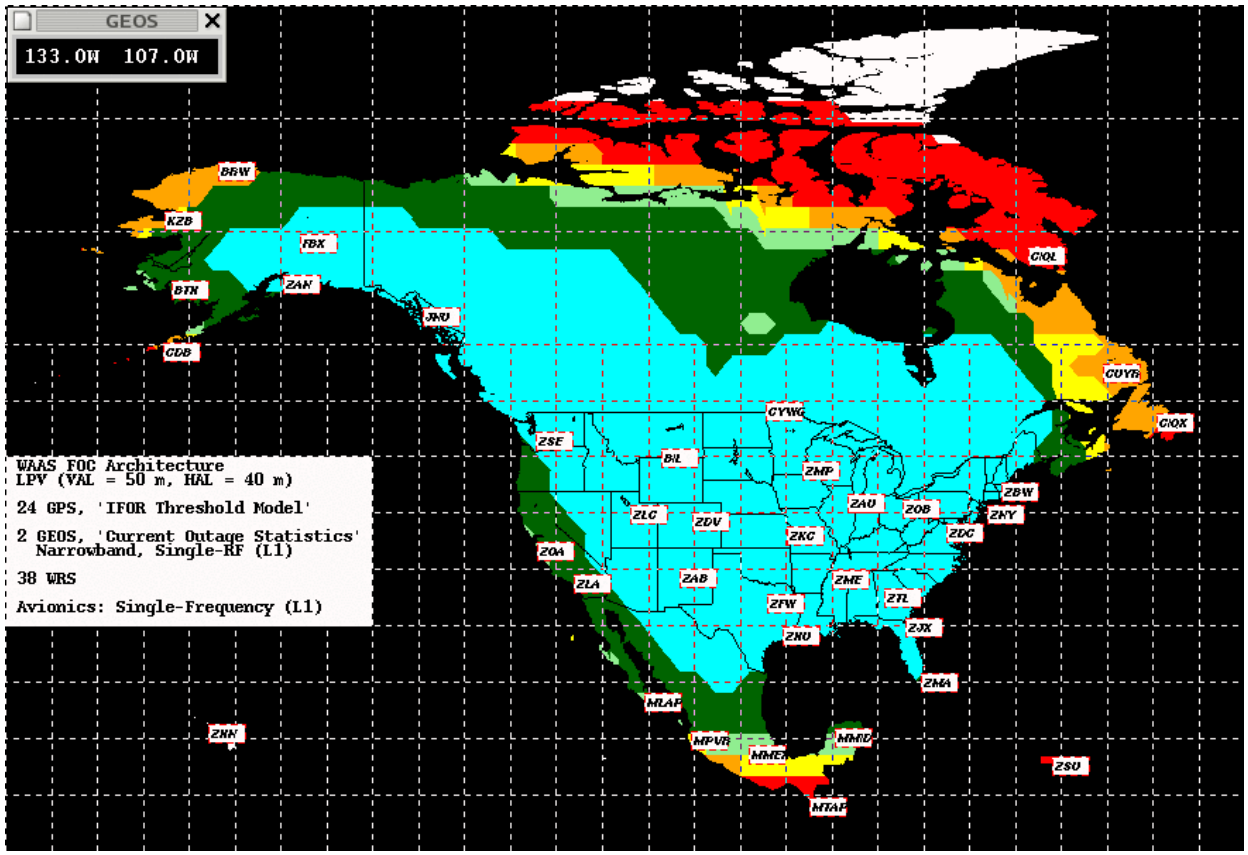
WAAS FOC
LPV service (VAL: 50 m, HAL: 40 m)

HIGHER AVAILABILITY



LOWER AVAILABILITY

38 WRS, 24 GPS, 2 GEO (133 W, 107 W)



24 hour average

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Extending WAAS Service

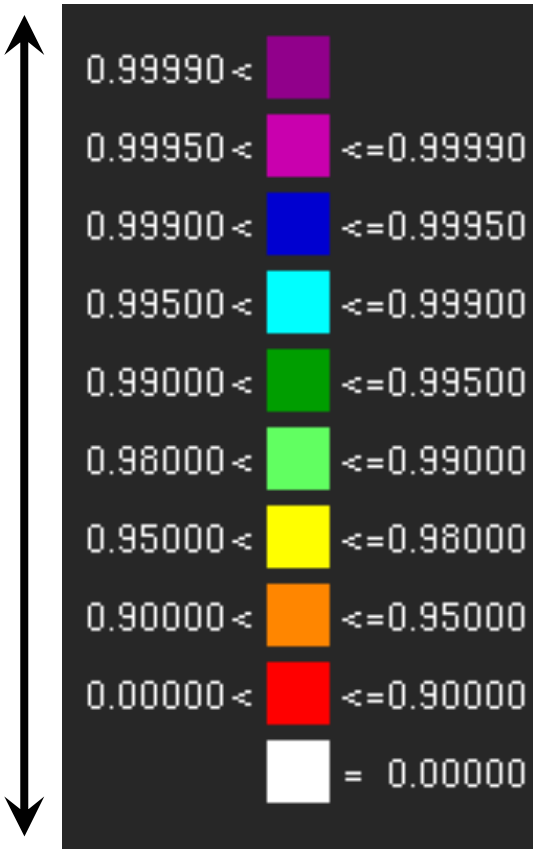
- **Central and South America**
  - **Current assumptions (near-term) for Final Operational Capability**
  - **Any WAAS performance availability for LPV?**

- **What future modifications to WAAS, beyond the FOC assumptions for LPV, could theoretically yield navigational benefits in Central and South America?**

- **How would these potential benefits be determined?**

WAAS FOC (based on current assumptions)
LPV service

HIGHER AVAILABILITY



LOWER AVAILABILITY

38 WRS, 24 GPS, 2 GEO (133 W, 107 W)

24 hour average

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SWAT

SWAT Background

- **SWAT**
  - **SBAS (Space-Based Augmentation System)**
  - **Worldwide**
  - **Availability**
  - **Tool**

- **Estimates WAAS performance by modeling availability of service, and possibly other measures, as experienced by avionics**

SWAT Modeling Capabilities

- **Accommodates various configurations of input data through user-selectable analysis options (examples):**
  - **System Architecture (e.g. IOC, FOC, beyond-FOC)**
  - **Navigation Service (e.g. LNAV/VNAV, LPV, GLS)**
  - **Analysis region (e.g. CONUS, Alaska, North America, etc)**
  - **WRS ground networks (e.g. IOC 25, FOC 38)**
  - **GPS constellations (e.g. Martinez 24, current 28)**
  - **GEOS longitudinal coordinates**
  - **Satellite attributes (e.g. bandwidth, frequency quantity and type, operational status)**
  - **Avionics characteristics (e.g. frequency quantity and type)**

SWAT Limitations

- **Some Limitations – No current modeling capability for:**
  - **Ground-based component reliability**
  - **Ionospheric storm activity**
  - **Effects of scintillation (loss of signal lock) along the geomagnetic equator**
  - **Real-time data processing**

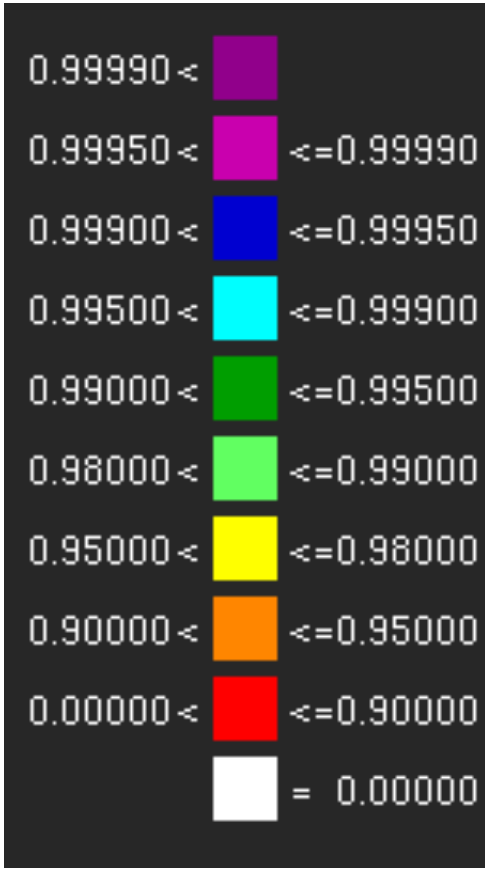
"Availability of Service"

- **Sampling-Locations (latitude and longitude, time)**
  - **Position errors**
- **Satellite Reliability**
- **Top Level – All satellites in view are operational**
  - **Do I have service?**
  - **Compute satellite probability**
- **Subsets – One or more of satellites in view have failed**
  - **Do I still have service?**
  - **Compute satellite probability**

“Availability of Service” (summary)

- SWAT models the total probability of availability of a specified service given satellite reliability models of various kinds at a sampling location in time and space

- Output consists of a color contour corresponding to the availabilities at sampling locations within the geographical analysis region
  - Snapshot (instantaneous time)
  - Average (24 hours)



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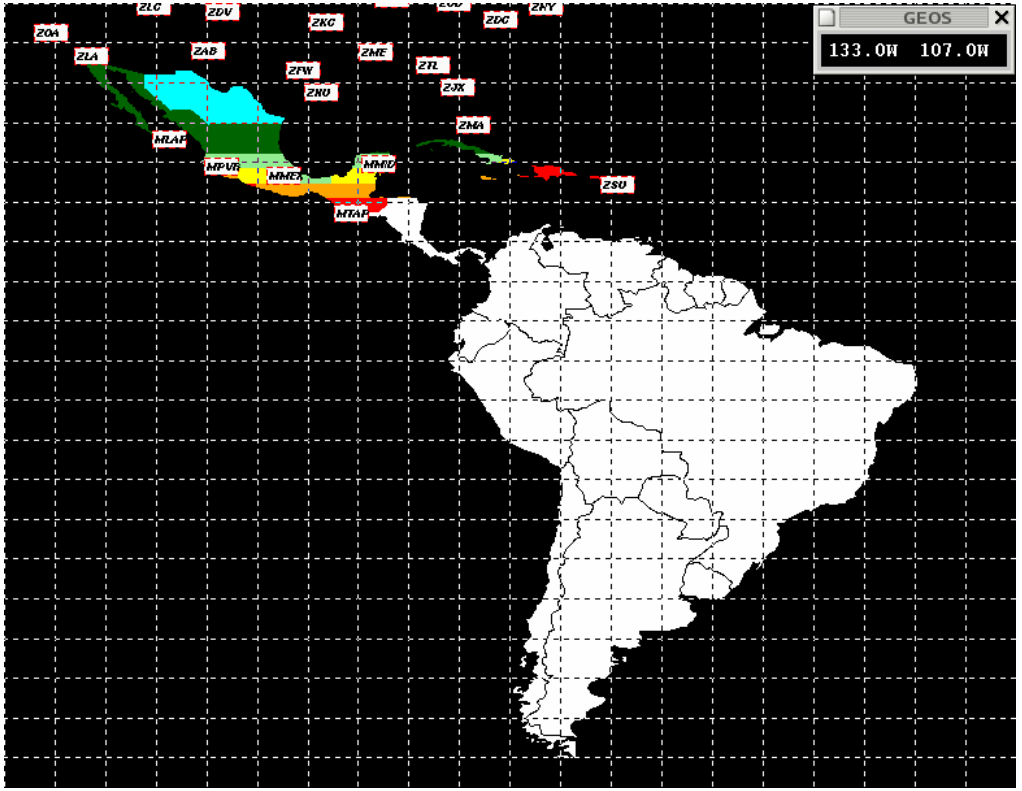
WAAS Analysis of Central and South America

Extending WAAS Service into Central and South America

- **What might WAAS LPV performance resemble in Central and South America with the assumed FOC architecture?**

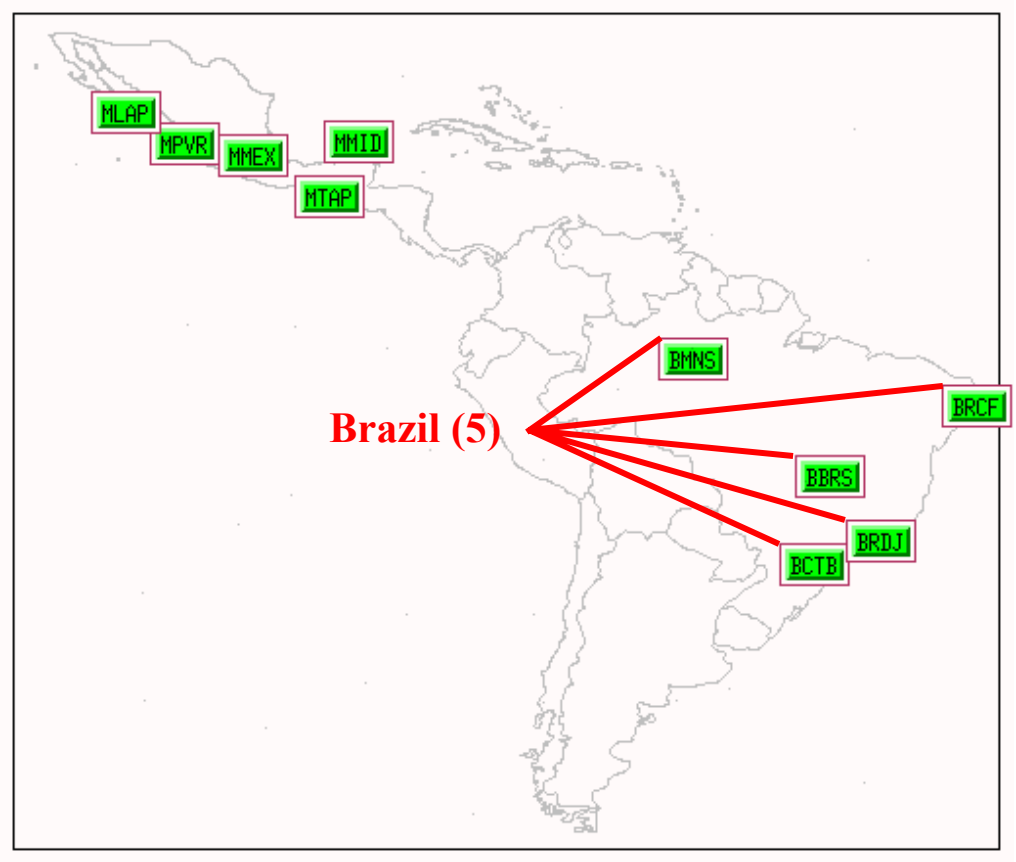
LPV service unavailable in nearly entire region



Beyond FOC: Future Modifications for analysis of Central and South America

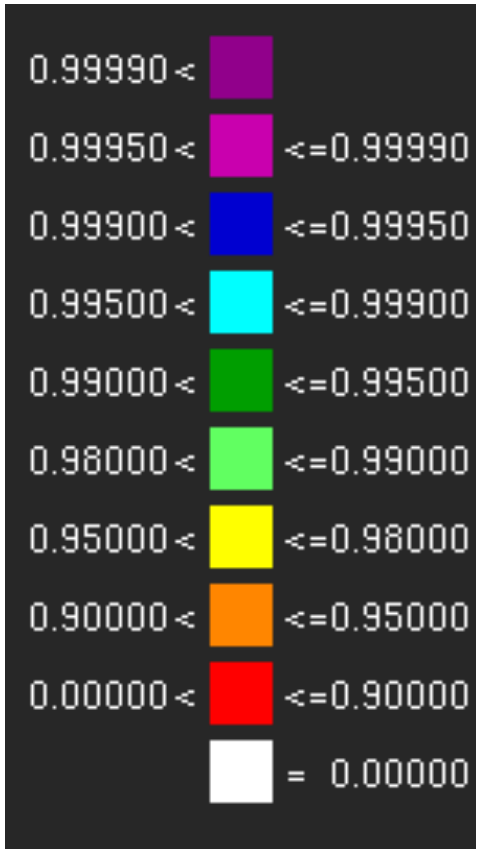
- System architecture: "Trusted"
  - Vs. "Untrusted"
  - Improved hardware with higher quality software certification in reference stations
  - Reduces assumed errors
- Avionics will use 2 frequencies (L1 & L5)
  - Ionospheric corrections computed by avionics
- Additional WAAS reference stations
  - Add 5 stations in Brazil
  - Add 3 stations in Chile
- Additional GEO satellite
  - Redundancy (coverage by more than one WAAS broadcast source)

5 Brazilian Reference Stations



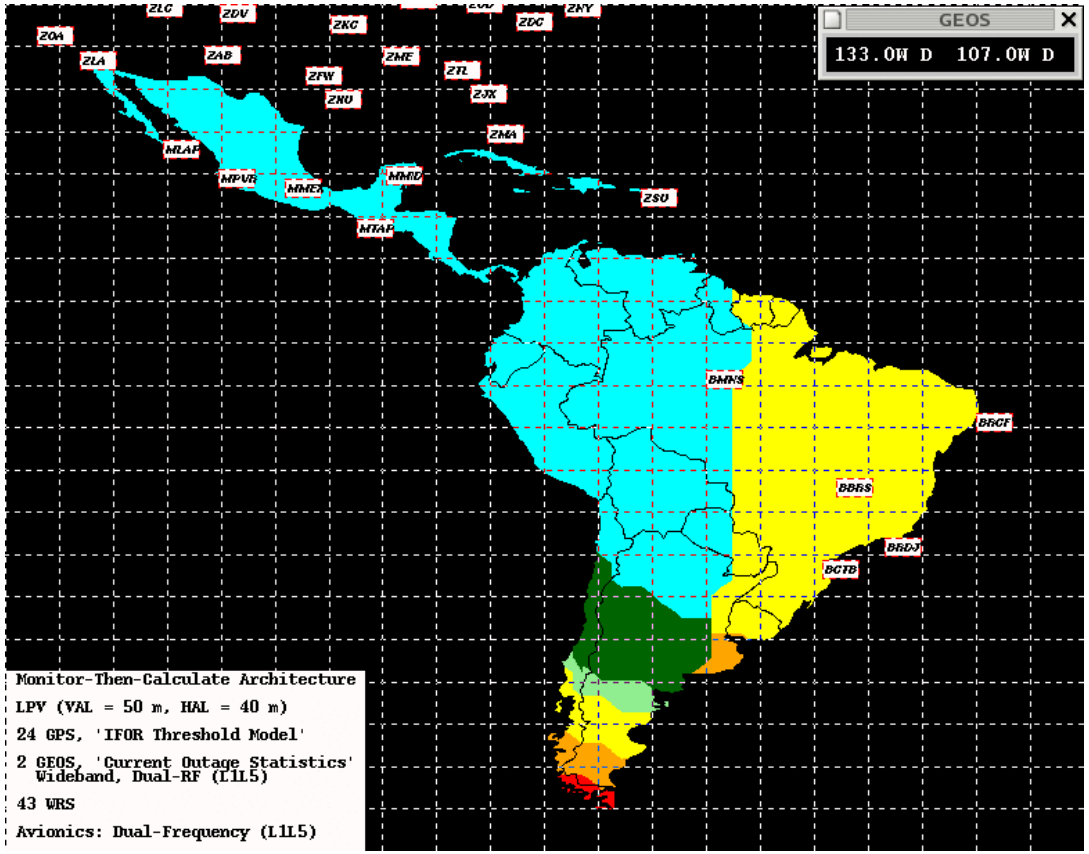
"Trusted" Architecture
Dual-Frequency (L1 & L5)
5 additional WRS in Brazil

HIGHER AVAILABILITY



LOWER AVAILABILITY

43 WRS, 24 GPS, 2 GEO (133 W, 107 W)



24 hour average

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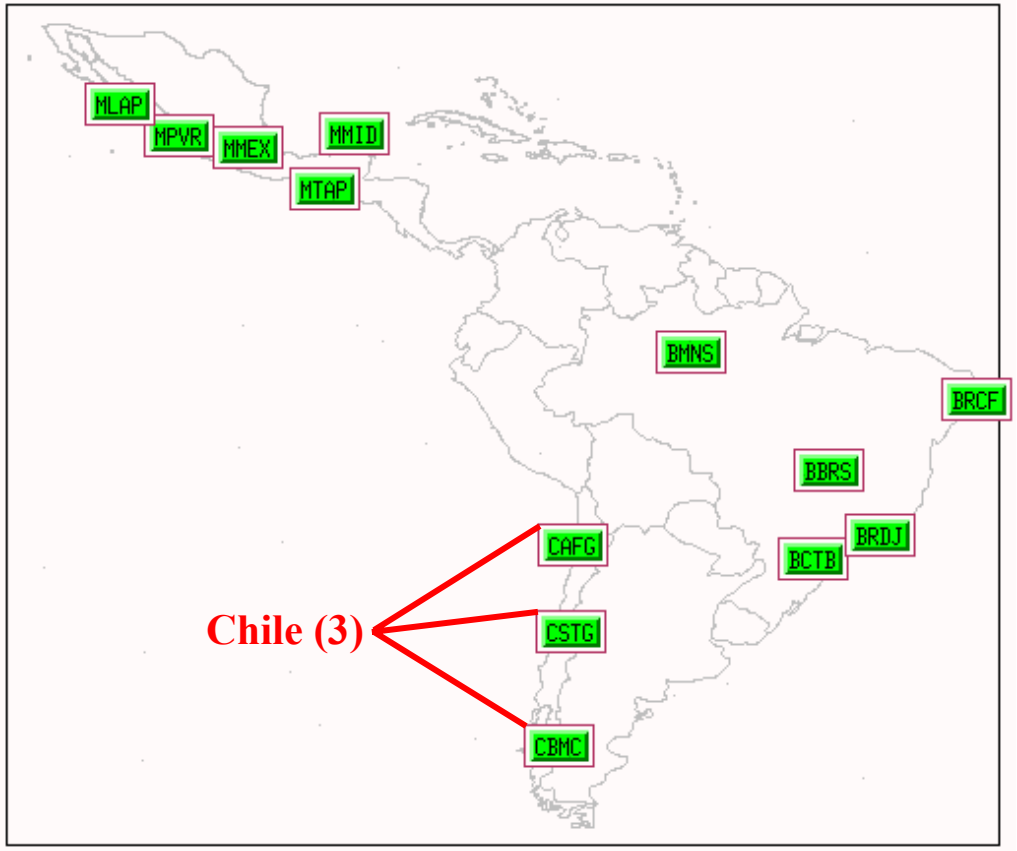
Add 3 Chilean Reference Stations



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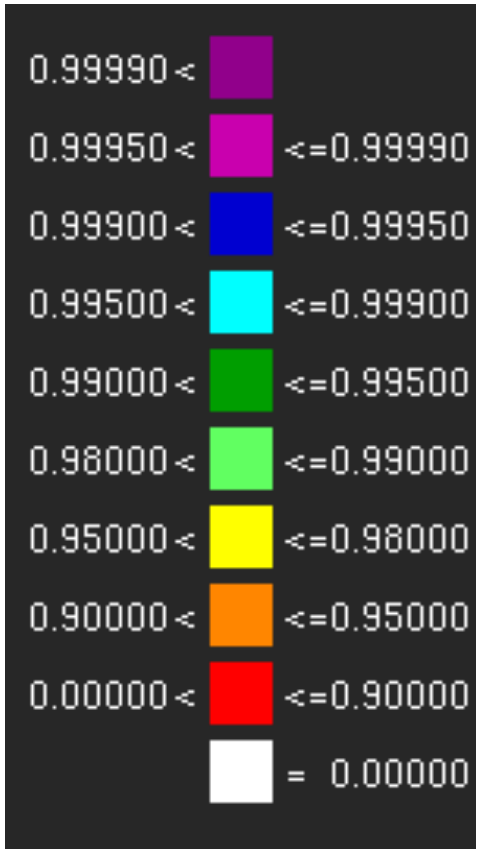
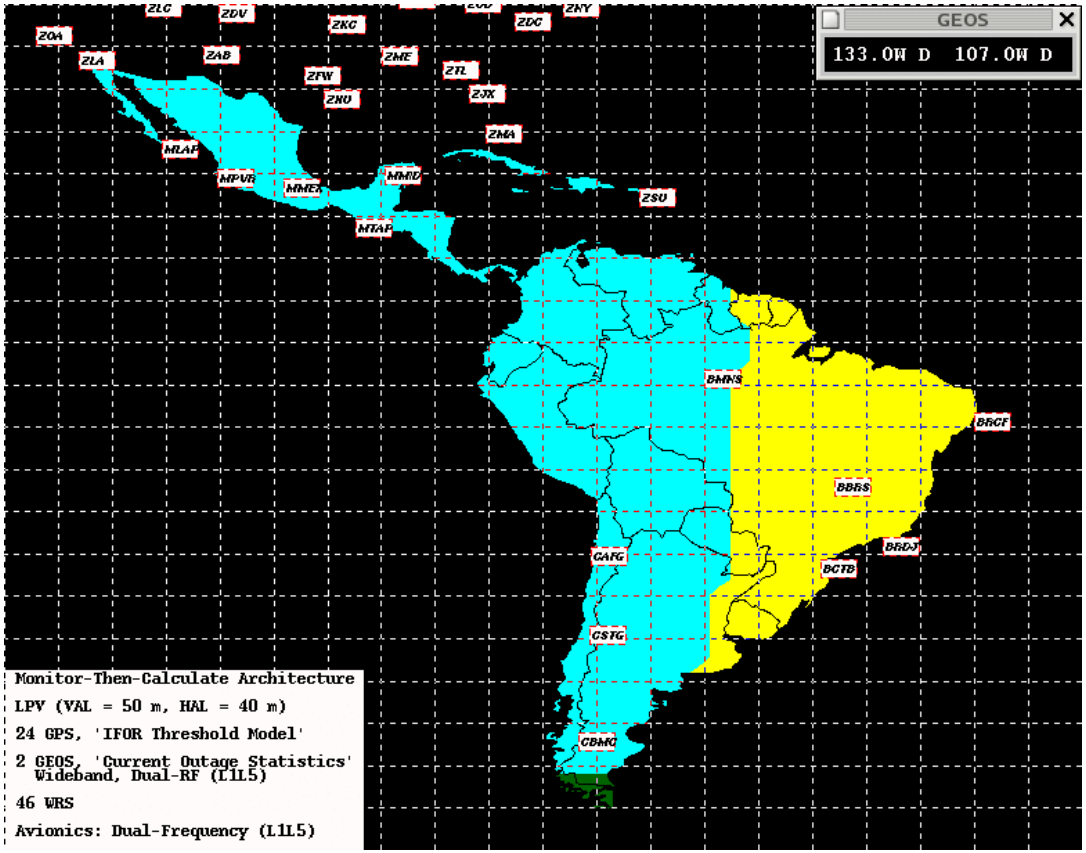
"Trusted" Architecture
Dual-Frequency (L1 & L5)
5 in Brazil, 3 additional WRS in Chile

HIGHER AVAILABILITY



LOWER AVAILABILITY

46 WRS, 24 GPS, 2 GEO (133 W, 107 W)



24 hour average

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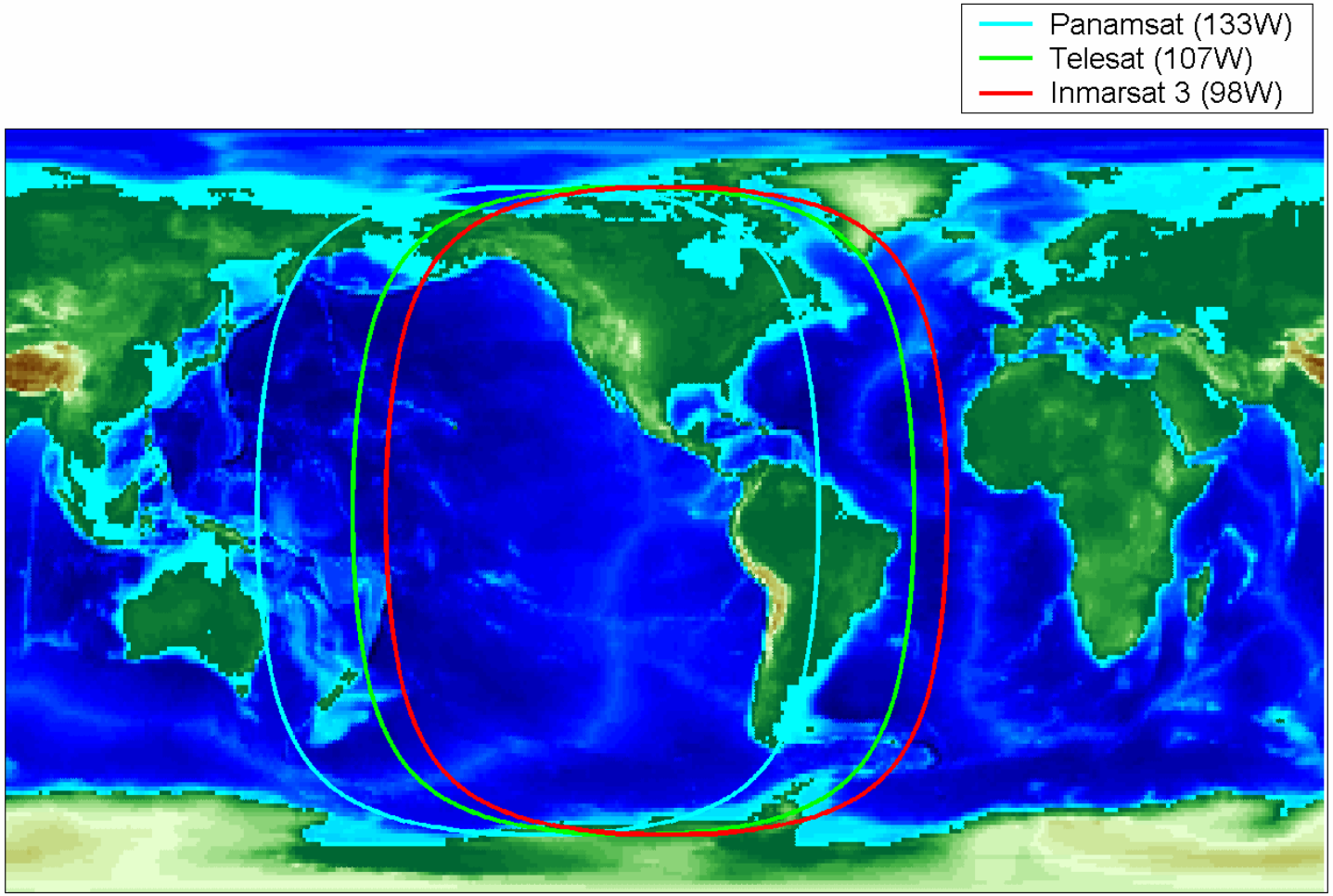
GEO Satellite Footprints for 133 W, 107 W, and 98 W



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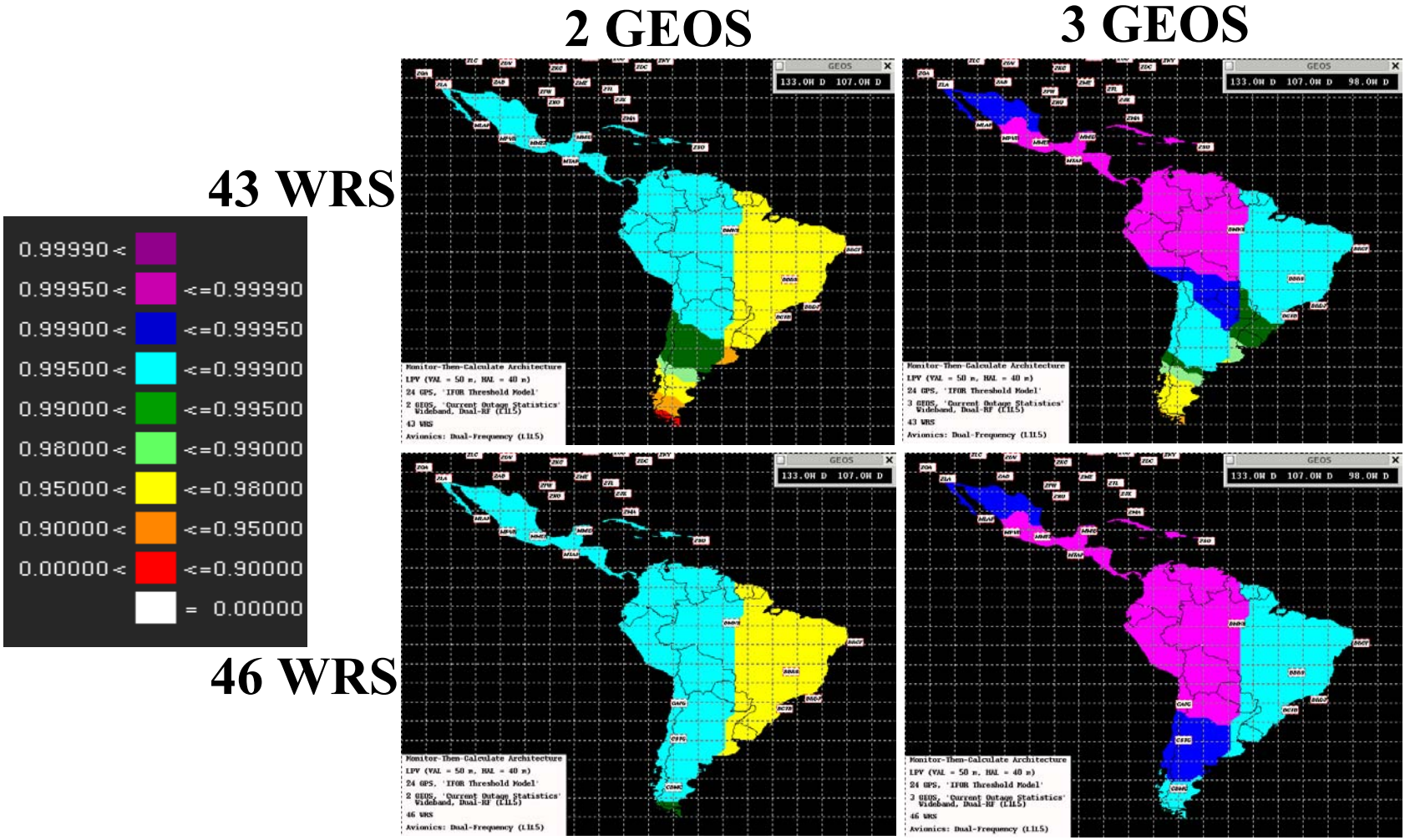
"Trusted" Architecture
Dual-Frequency (L1 & L5)
Full Comparison with additional GEO (98 W)



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Review Results

- **Significant LPV availability (>= 95%) with extended WAAS in Central and South America**
  - **“Trusted”Architecture**
    - **Additional algorithmic and parametric improvements**
  - **Dual-Frequency avionics**
    - **Ionospheric threat model need not be defined**
  - **Additional reference stations**
    - **Increase measurements yields error reduction**

- **Higher LPV availability (>= 99%) with additional GEO**
  - **Additional source of WAAS broadcast yields higher probability of success**

Recommendations for future analysis

- Simulate environmental effects – scintillation
- Varied reference station configurations
- Investigate more stringent navigational criteria
  - GLS (VAL: 12 m, HAL: 40 m)
- Develop ionospheric threat model
  - Analyze independent SBAS vs. extended WAAS
  - Compare and contrast performance benefits vs. cost

Closing

- **Benefits of CAASD's SWAT model:**
  - **Resource analysis tool**
  - **Operational analysis tool**

- **International expansion capabilities – SWAT analysis not limited to U.S. WAAS and GPS**
  - **MSAS**
  - **EGNOS**
  - **GRAS**
  - **Gagan**
  - **Galileo**