



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Modeling Scintillation Effects on L1/L5 SBAS Availability in North and South America

*The Atmosphere and its Effect on GNSS
Systems*

14 to 16 April 2008

Santiago, Chile

Dr. M. Bakry El-Arini

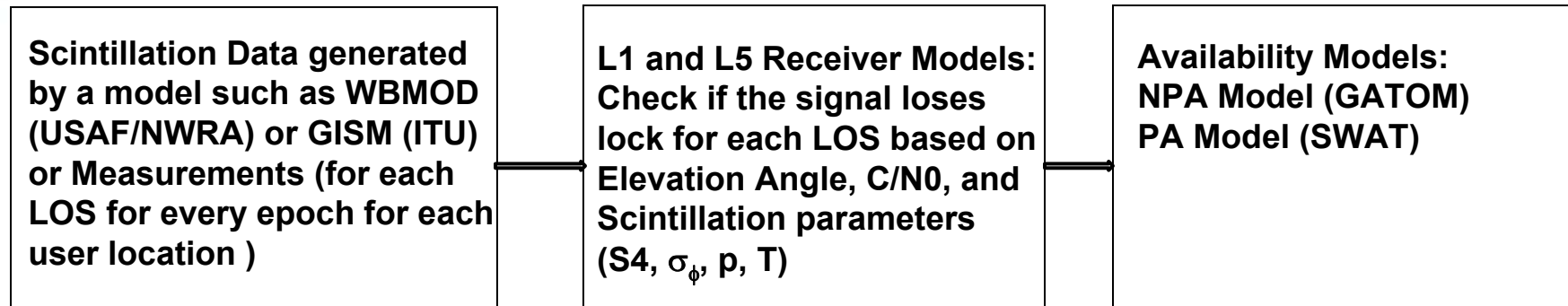


Overview

- **Background**
- **Methodology for Modeling Ionospheric Scintillation Effects in MITRE's SBAS Availability Models**
- **Example Results of Modeling Ionospheric Scintillation Effects on Availability for L1/L5 SBAS in North America for nonprecision approach**
- **Example Results of Modeling Ionospheric Scintillation Effects on Availability for L1/L5 SBAS in North America for LPV approach**



Summary of the Process



Acronyms:

GATOM: GPS Air Traffic Operations Model
GISM: Global Ionospheric Scintillation Model
ITU: International Telecommunication Union
LOS: Line Of Sight
NWRA: North West Research Associates, Seattle, WA, USA
SWAT: SBAS Worldwide Availability Tool
USAF: United States Air Force
WBMOD: Wide Band Model



Methodology for Modeling Ionospheric Scintillation Effects in MITRE's SBAS Availability Models

*Originally Prepared by
Dr. M. Bakry El-Arini, Dr. Chris Hegarty
Dr. Michael Tran, Ing. J. P. Fernow*



Assumptions

- **SBAS user equipment will NOT likely be required to support a mixed mode**
 - E.g., dual-frequency measurements from satellites and single-frequency measurements from other satellites
 - Some user equipment might support this mode, but likely not a minimum requirement
- **MITRE availability models model the user equipment as one of three cases**
 - All satellites, including GEOs, are dual-frequency
 - All satellites are L1 only
 - All satellites are L5 only
- **Notes**
 - Future user equipment requirements might include additional cases
 - Ground reference stations are dual-frequency for all cases



A Simple Logic for Availability Calculation for L1(C/A)/L5 Dual-Frequency SBAS *1 of 2*

- **Calculate availability for L1/L5 dual-frequency user and WRSs without scintillation in North America**
 - Normal mode is both L1(C/A) and L5 are locked for all line of sights (LOSs) to satellites visible from the service volume
 - This is used as a baseline
- **Calculate availability with different levels of scintillation (see next few charts for details)**
 - **WAAS Reference Stations (WRSs)**
 - Dual-frequency (DF) mode for each LOS to GPS satellites
 - If lock is lost on either L1 or L5 or both, then don't use this LOS in computing HPL or VPL if the satellite is a GPS satellite
 - WRSs use single-frequency (SF) GEOs



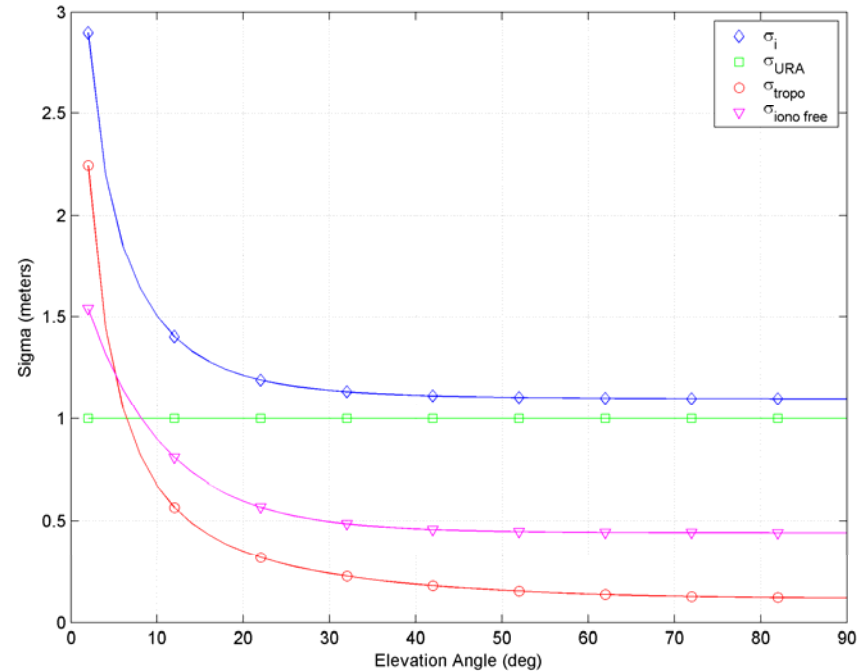
A Simple Logic for Availability Calculation for L1(C/A)/L5 Dual-Frequency SBAS *2 of 2*

- **SBAS user equipment**
 - **Pure L1/L5 dual-frequency (DF) mode**
 - **If either L1 or L5 or both is/are lost for a particular satellite LOS, then don't use this satellite when computing HPL or VPL**
 - **L1 or L5 single frequency (SF) modes**



L1/L5 GPS Dual-Frequency User Error Model (Without Scintillation)

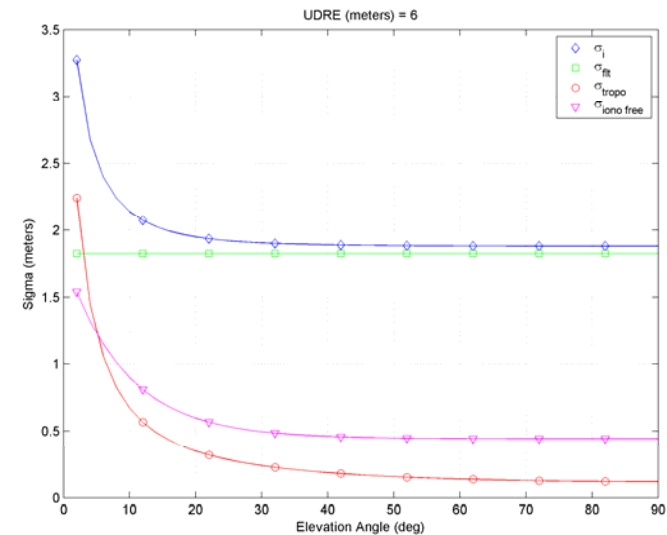
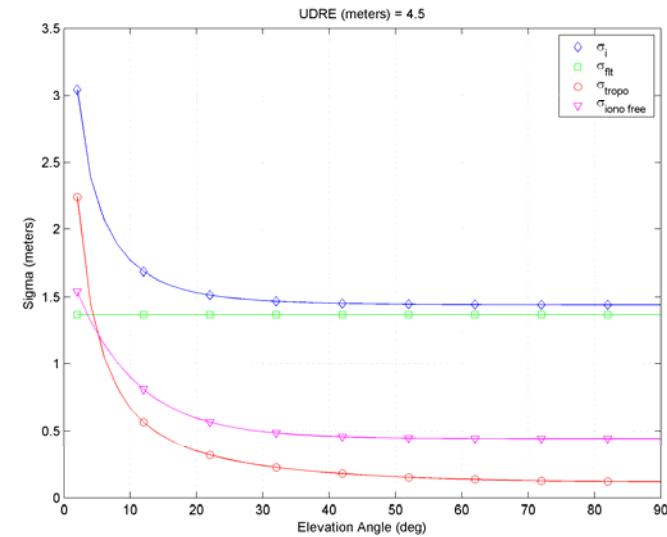
- Chart shows different components of user equipment dual-frequency range error





SBAS L1/L5 Dual-Frequency User Error Model

- These charts show different components of SBAS user equipment dual-frequency range error at two fixed User Differential Range Error (UDRE) as examples
- Error for Fast and long-term correction (σ_{flt}) = $UDRE * \delta UDRE / 3.29$
- (Assume UDRE = 4.5m & 6m, $\delta UDRE = 1$)





Single-Frequency Mode User Equipment Receiver Error Models

- **L1 single-frequency mode user equipment receiver error model**
 - RTCA DO-229D for airborne receiver

- **L5 single-frequency mode user equipment receiver error model**
 - Similar algorithms to L1 as in RTCA DO-229D for airborne receiver
 - Some differences due to larger ionospheric delay and error; see next page



A Simple Logic for Loss of Lock for L1 C/A GPS and GEO Satellites

- For each WRS and user location
 - For every snapshot, every line of sight (LOS) for every visible GPS and GEO satellites, calculate IPP location and elevation angle
 - Calculate $C/N0_{C/A}$ (GPS) or $C/N0_{C/A}$ (GEO)
 - Calculate scintillation parameters at L1 (1575.42 MHz) using a scintillation model (WBMOD) (Measurements can be used if available)
 - Amplitude scintillation: $S4(L1)$
 - Phase scintillation: $\sigma_{\phi}(L1)$, $T(L1)$ (strength of power spectral density at 1 Hz), $p(L1)$ (slope of power spectral density)
 - Calculate Carrier Tracking error ($\sigma_{\phi_{\epsilon}}(L1)$)
 - If $\sigma_{\phi_{\epsilon}} > \text{threshold}$, declare loss of lock for this LOS. This LOS should not be used in any availability calculations
 - If $\sigma_{\phi_{\epsilon}} \leq \text{threshold}$, then this LOS did not lose lock, calculate code tracking error due to scintillation and RSS it with other errors. We will assume this code tracking error = 0 in this initial phase of implementation)



A Simple Logic for Loss of Lock for L5 GPS and GEO Satellites

- **Similar to L1 with the following additional assumptions**
 - **GPS: assume 50% power in the Q-channel and 50% in the I-channel**
 - **GEO: assume 100% power in the I-channel**



Receiver Lock Loops Thresholds (Degrees)

	L1 (C/A)		L5	
	Ground Rx	Airborne Rx	Ground Rx	Airborne Rx
	GPS	10.5	10.0	19.7
GEO	10.5	10.0	10.5	10.0



Examples of Modeling Ionospheric Scintillation Effects on Availability for L1/L5 SBAS in North America: NPA Case

Originally Prepared by Ing. Tom Hsiao



Overall Assumptions

- **24 GPS Martinez constellation**
- **2 GEOs at 133°W and 107°W**
- **38 L1/L5 WAAS Reference Stations in North America, Hawaii, and Puerto Rico**
- **IFOR threshold outage probability statistics for GPS**
 - **No failures on operating GEO satellites**
- **HAL = 556m (NPA), URA = 4.5m**
- **24-hour average with 1-minute sampling interval**
- **User grid 2 x 2 degrees**

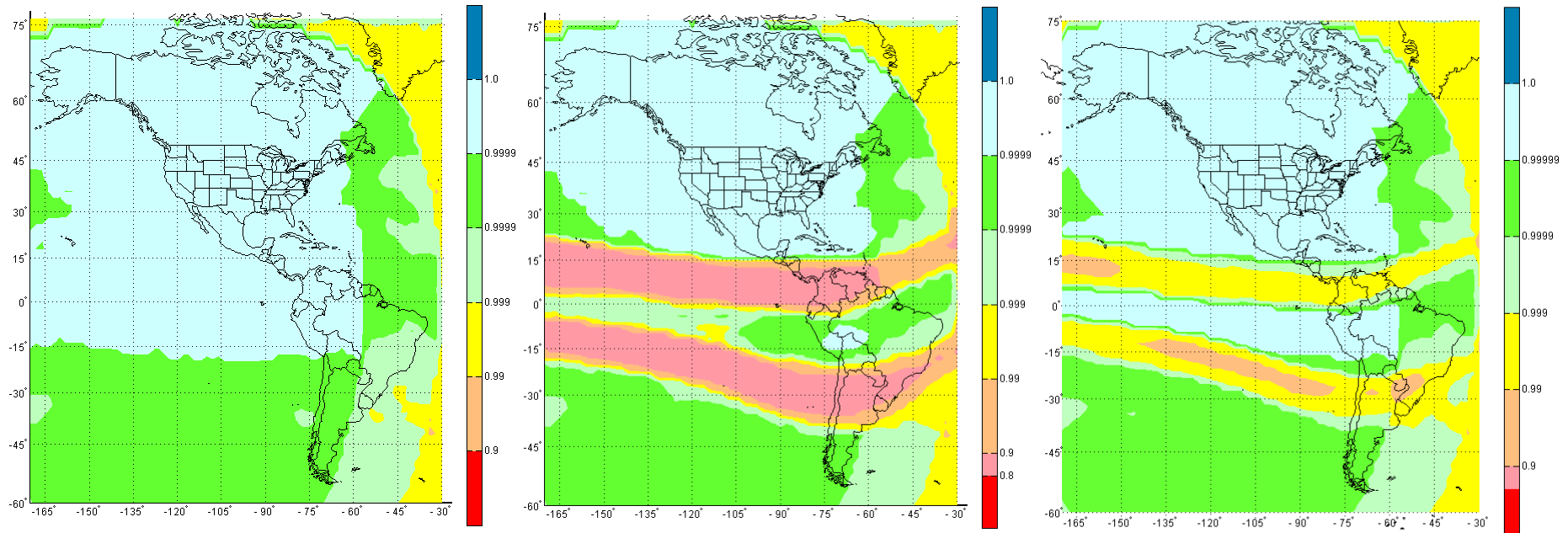


Scintillation Assumptions

- **Date: September 15 (Day of Year = 258)**
 - In equatorial region, worst scintillation occurs during Equinox months
- **Sunspot number (SSN) = 150 (\approx peak of solar cycle)**
- **KP geomagnetic index = 1 (quiet ionosphere, no storm)**
- **WBMOD (V15.03, dated July 8, 2005) is used to generate scintillation parameters for each line of sight**
 - The 95th percentile values of S4 (a measure of amplitude scintillation) and σ_ϕ (a measure of phase scintillation) are generated
- **A receiver model determines whether the generated S4 and σ_ϕ values cause a loss of lock on the satellite signal**
 - The satellite is not used in the position solution is due to the loss of lock



L1/L5 Dual-Frequency



No Scintillation

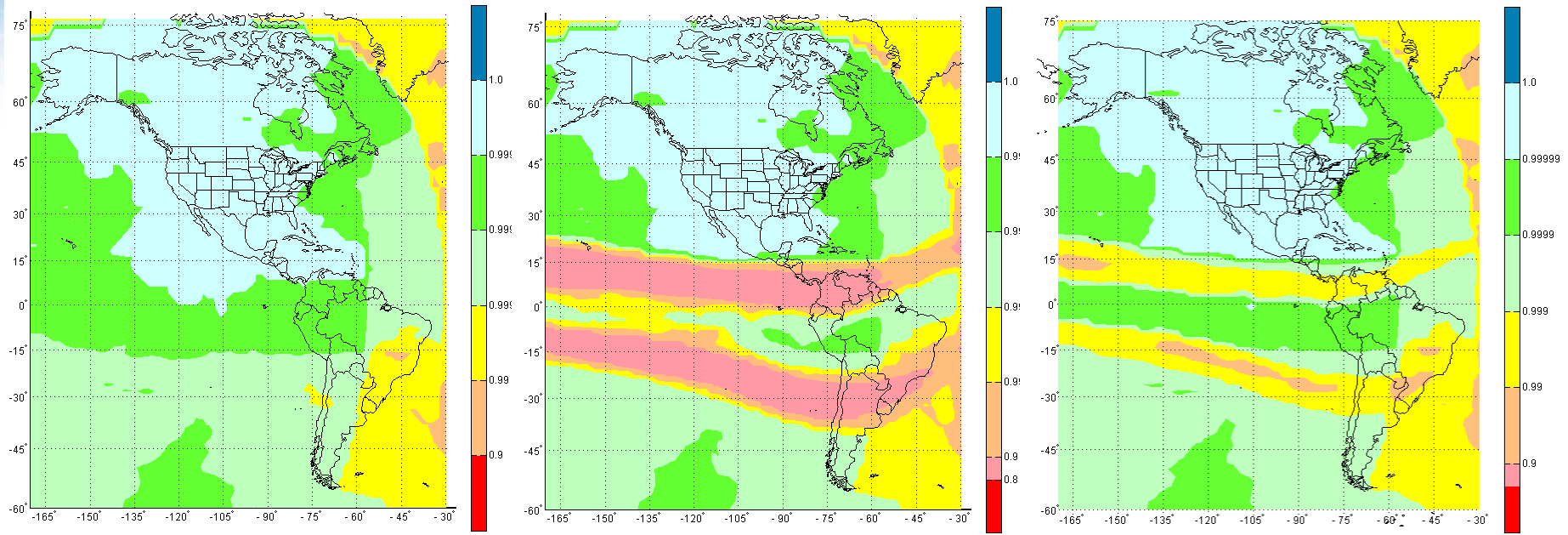
**95th Percentile Scintillation
without Reacquisition**

**95th Percentile Scintillation
with Reacquisition**

These results may indicate lower availability than will be experienced in practice, since WBMOD does not model the patchiness of ionospheric scintillation.



L1 Single-Frequency



No Scintillation

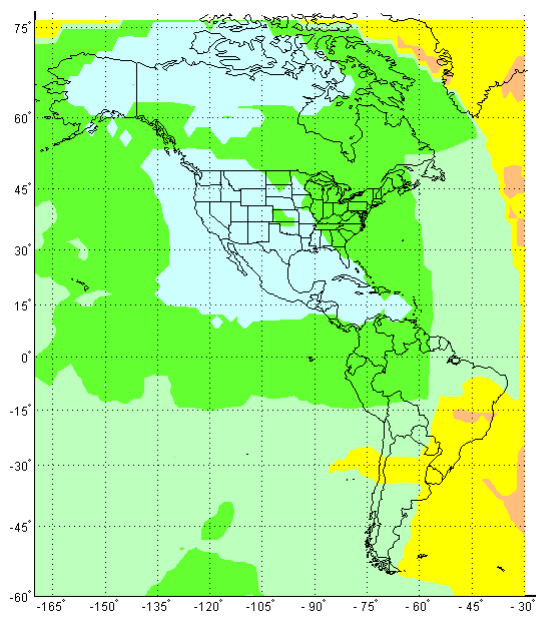
**95th Percentile Scintillation
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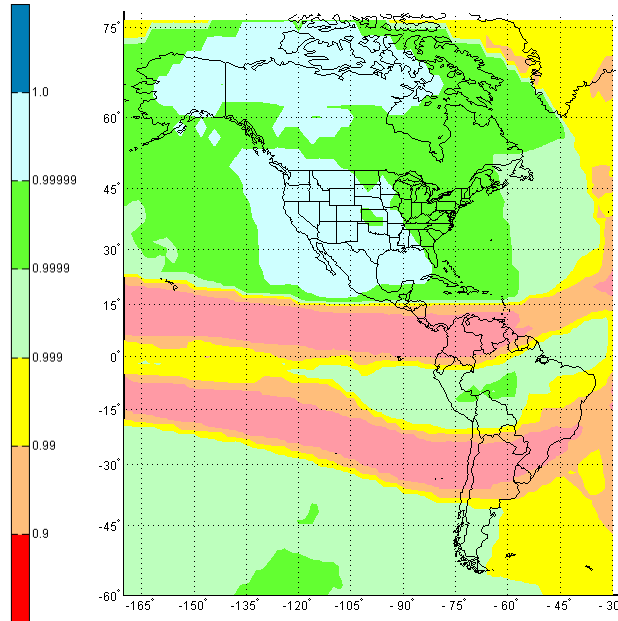
These results may indicate lower availability than will be experienced in practice, since WBMOD does not model the patchiness of ionospheric scintillation.



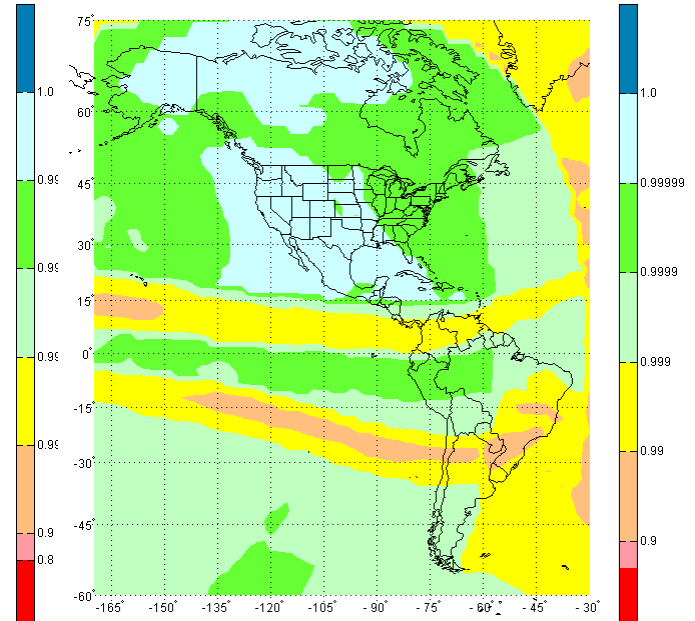
L5 Single-Frequency



No Scintillation



**95th Percentile Scintillation
without Reacquisition**



**95th Percentile Scintillation
with Reacquisition**

These results may indicated lower availability than will be experienced in practice, since WBMOD does not model the patchiness of ionospheric scintillation.



Observations

- **As expected, in the absence of scintillation, the NPA availability provided by pure dual-frequency mode is higher than the availability provided by either pure single-frequency L1 mode or L5 mode**
- **With scintillation, the availability of NPA service provided by pure dual-frequency mode is worse than the availability of L1 or L5 single-frequency mode in the affected areas (anomaly regions)**
 - **At a user location, for any line of sight (LOS) and at any snapshot, if the dual-frequency receiver loses lock on one or both frequencies, this LOS is not used in the position calculation.**



Example Results of Modeling Ionospheric Scintillation Effects on Availability for L1/L5 SBAS in North America: LPV Case

*Originally Prepared by
Ing. Deihim Hashemi
Ing. Michael P. McLaughlin
Ing. Pauline Yen*



Overall Assumptions

1 of 2

- **24 GPS Martinez constellation – broadcasting L1/L5**
- **2 GEOs at 133° W and 107° W**
 - Dual-Frequency L1/L5
 - 4.5 meters UDRE (constant)
- **38 WAAS reference stations (WRS) – L1/L5 compatible**
- **Reliability Models**
 - GPS: IFOR Threshold probability statistics
 - GEO: No Failures



Overall Assumptions

2 of 2

- **LPV Alert Limits**
 - Vertical 50 meters/Horizontal 40 meters
- **24-hour average with 5-minute sampling interval**
- **SWAT does not model ionospheric storms**
 - Contribution to LPV unavailability is estimated to be 0.00075 at middle latitudes in the US
- **LPV results may show lower availability that will be experienced in actual practice**
 - WBMOD does not account for patchiness of ionospheric scintillation
 - SWAT does not model reacquisition



Ionospheric Constraint Comparison

- **Case 1: No Constraint**
 - All IPPs, whether generated from WRS-Satellite or User-Satellite pairings, will be included in all calculations
- **Case 2: Existing Slant-Line Constraint**
 - See slide 26 for description
- **Case 3: Scintillation Model Constraint**
 - See slide 17 for scintillation assumptions
 - Slant-Line constraints are removed from this case
- **Analysis will be conducted using varying user equipment frequency capability**
 - L1 Single-Frequency
 - L5 Single-Frequency
 - L1/L5 Dual-Frequency



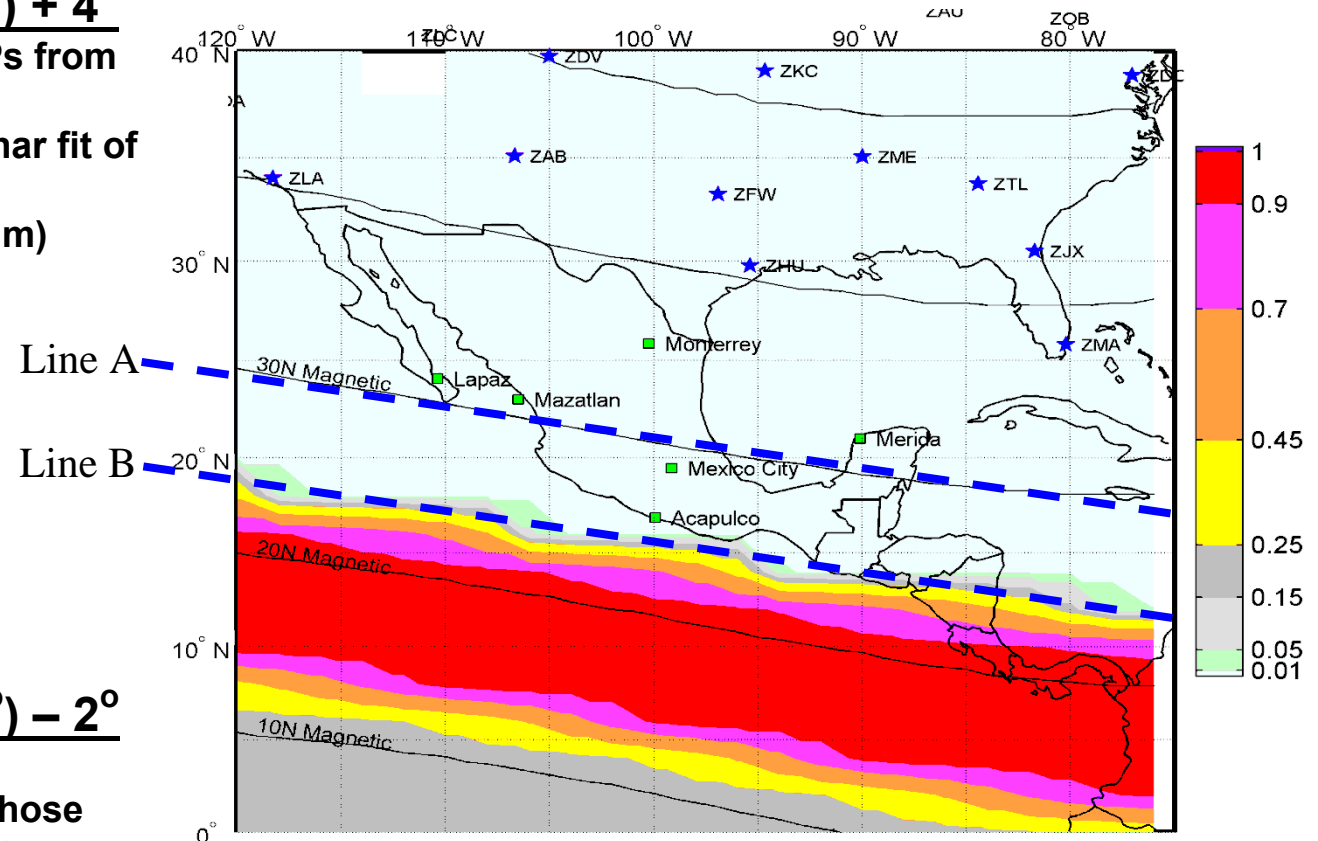
Slant-Line Model Constraint

A: $Lat^{\circ} = (-0.175 * Lon^{\circ}) + 4^{\circ}$

- Apply to WRS-generated IPPs from reference stations in Mexico
- Discard these IPPs from planar fit of all IGPs in the mask (i.e. no contribution to GIVE algorithm)
- UDRE algorithm unaffected

B: $Lat^{\circ} = (-0.175 * Lon^{\circ}) - 2^{\circ}$

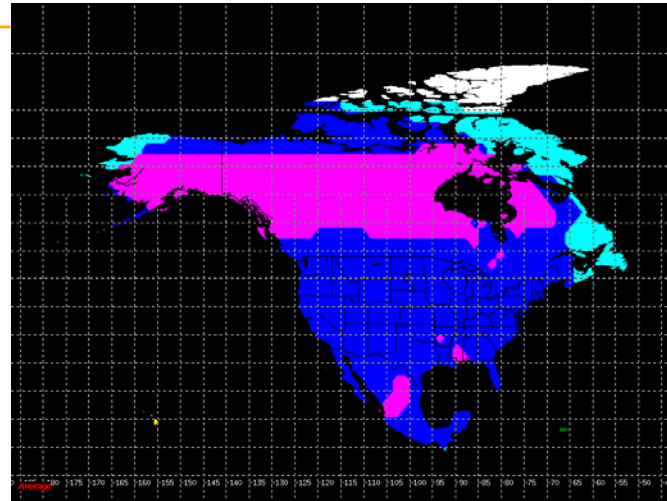
- Apply to IGPs in the mask
- Raise the $GIVE_{Floor}$ value of those IGPs from 3 meters to 15 meters



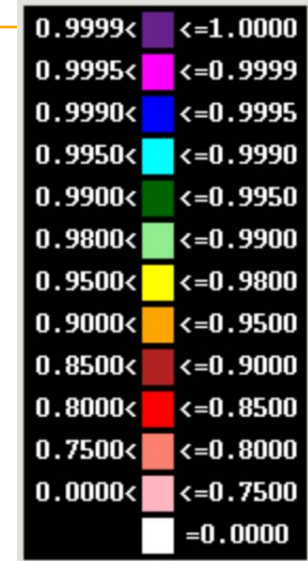
S4 is the normalized standard deviation of the variation of the intensity of the received signal. S4 = 0 means no scintillation, S4 = 1.0, means severe scintillation. Severe scintillation can happen after local sunset during the peak of solar cycle.



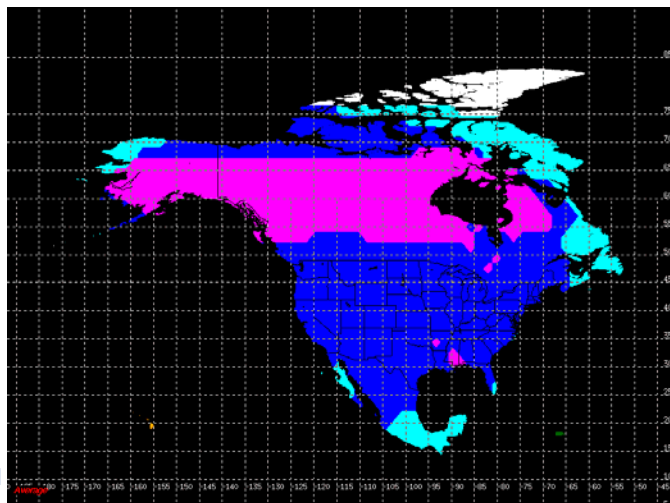
L1/L5 Dual-Frequency SBAS User Equipment Mode Full Comparison



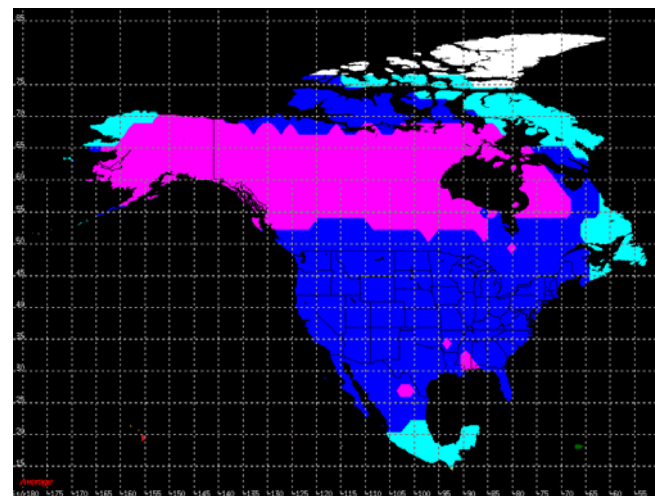
No Ionospheric Constraints



Slant-Line Model without Scintillation

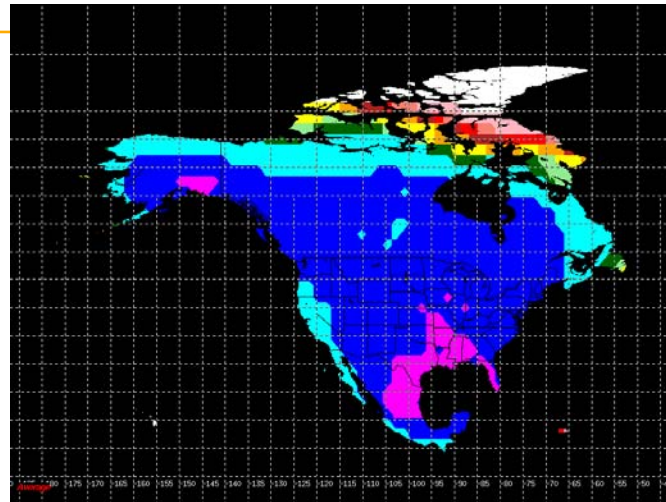


Scintillation without Slant Line (95th Percentile)

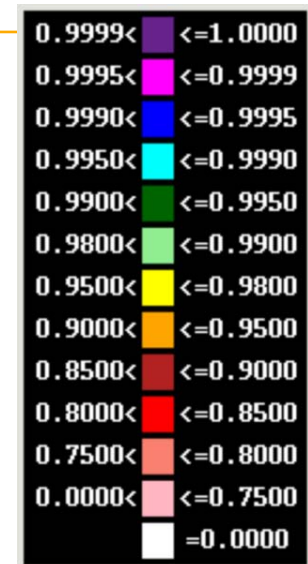




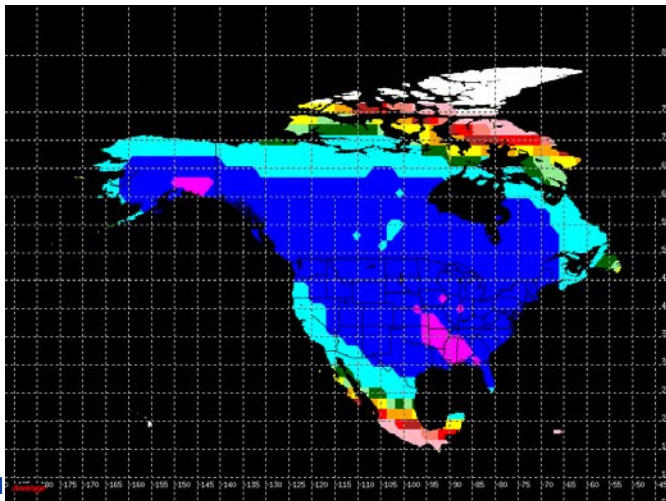
L1 Single-Frequency SBAS User Equipment Mode Full Comparison



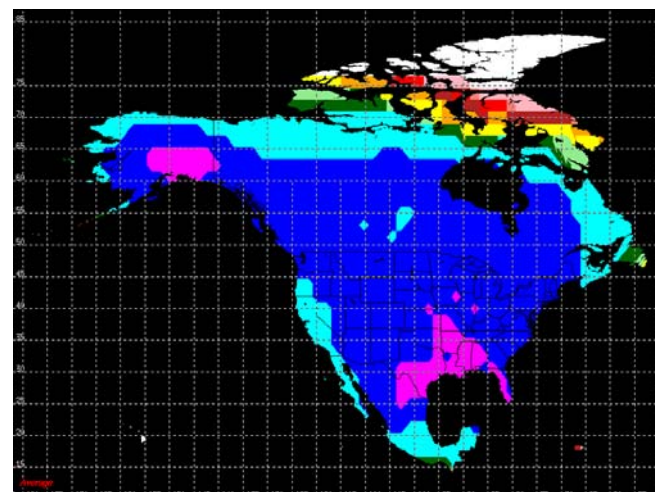
No Ionospheric Constraints



Slant-Line Model without Scintillation

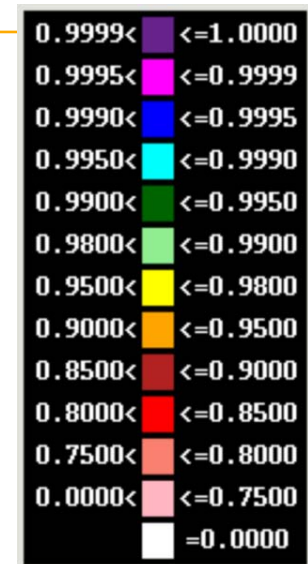
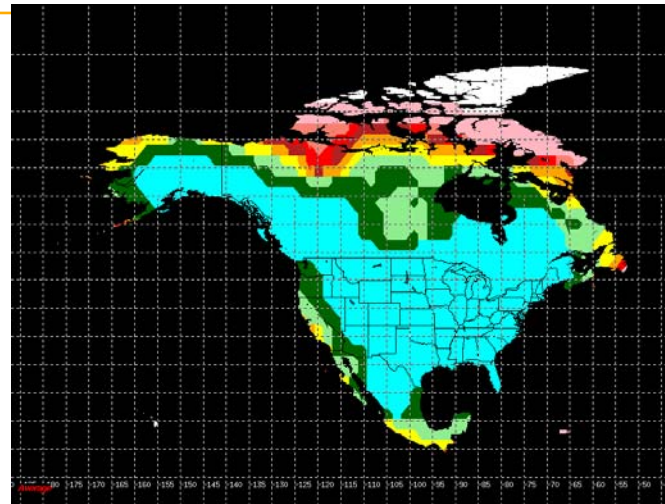


Scintillation without Slant Line (95th Percentile)



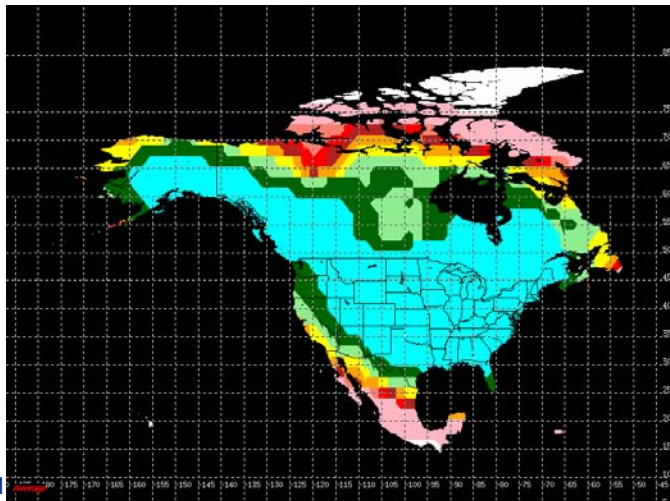


L5 Single-Frequency SBAS User Equipment Mode Full Comparison

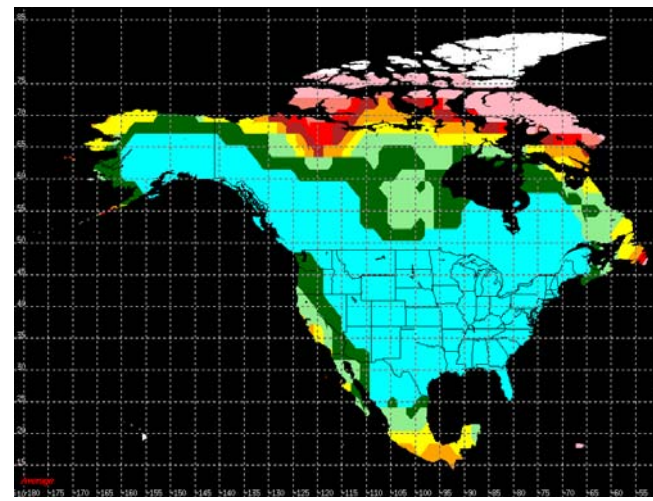


No Ionospheric Constraints

Slant-Line Model without Scintillation



Scintillation without Slant Line (95th Percentile)





Additional Analysis for the Northern Equatorial Region

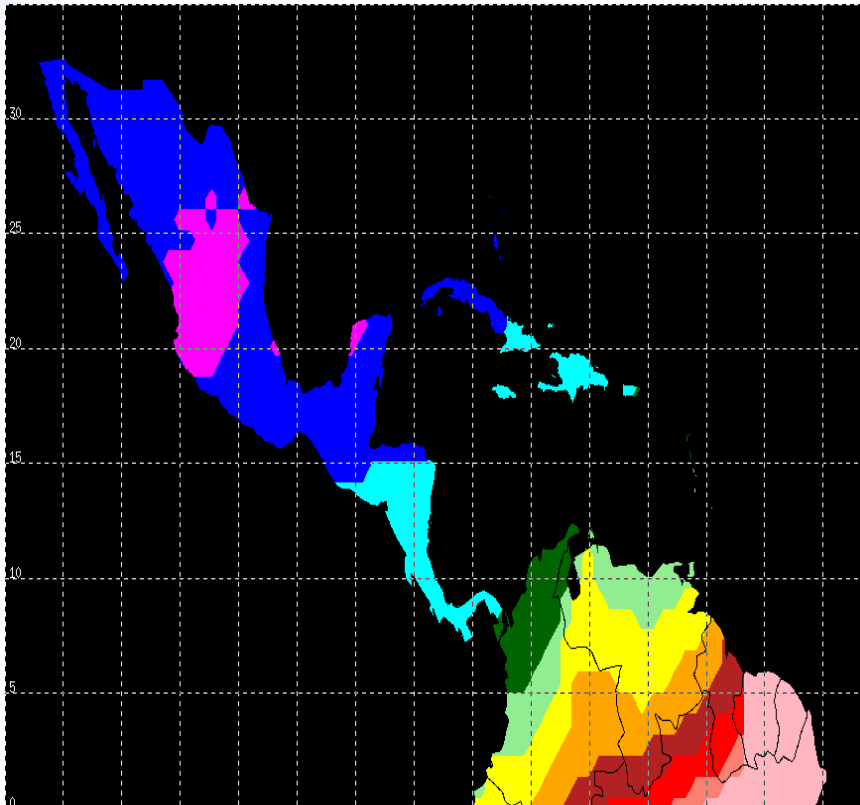


Adjustments to Analysis Assumptions

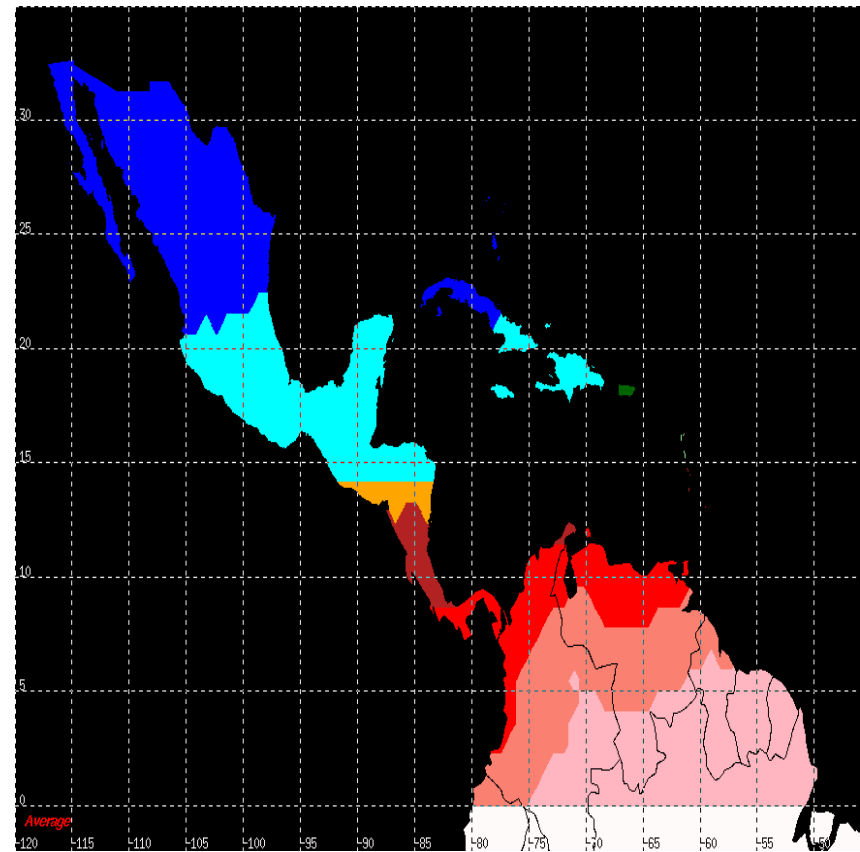
- **Change to Release 8/9 system architecture**
 - Universal IGP mask (corrections available for all IGP)
- **Ionospheric constraint scenarios**
 - No constraint
 - Scintillation Model constraint
- **Analysis region**
 - Central America
 - Caribbean
 - Northern South America (down to equator)



L1/L5 Dual-Frequency SBAS User Equipment Mode No Ionospheric Constraints



Without Scintillation

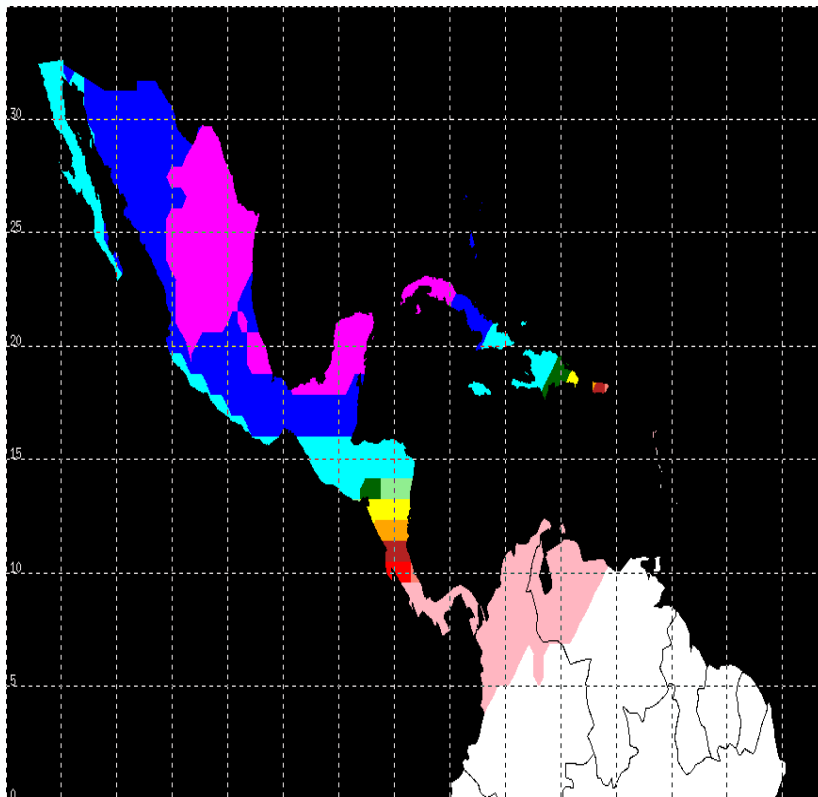


With 95th Percentile Scintillation

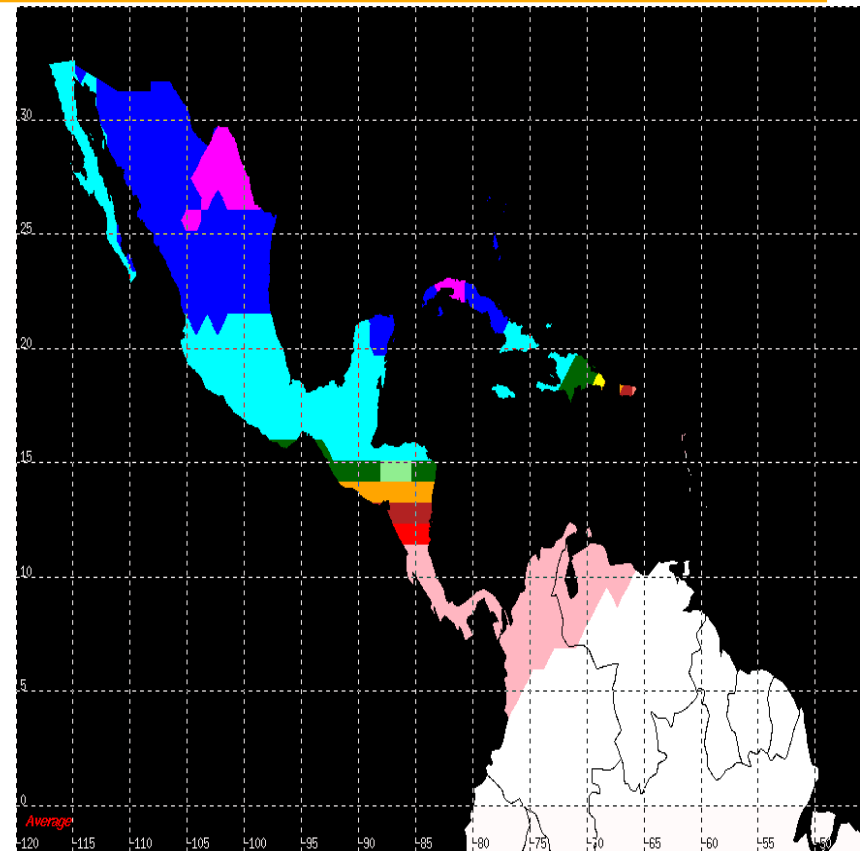




L1 Single-Frequency SBAS User Equipment Mode No Ionospheric Constraints Modeled



Without Scintillation

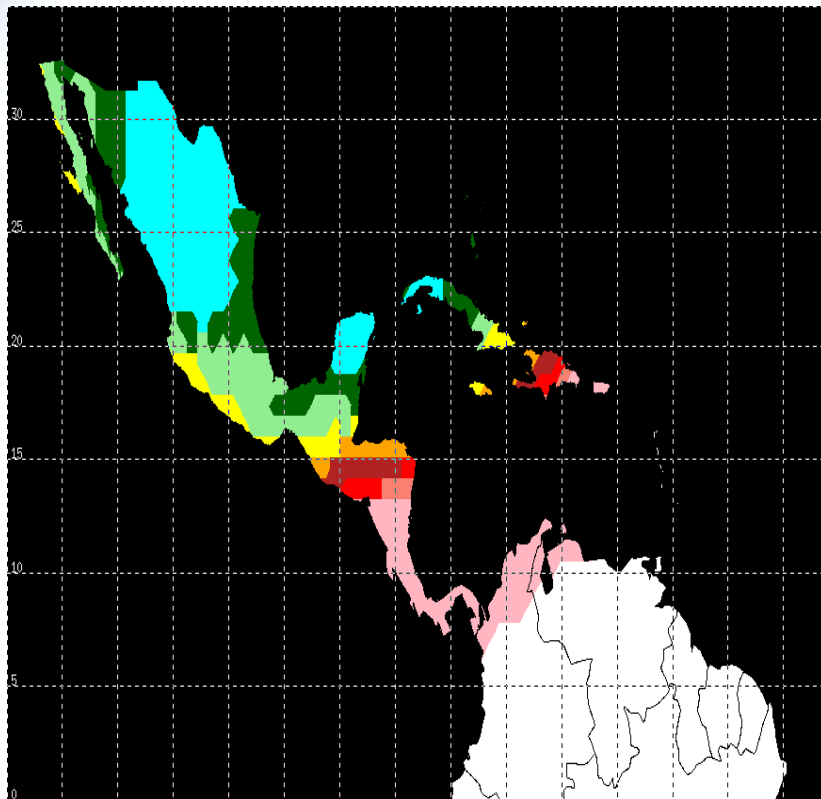


With 95th Percentile Scintillation

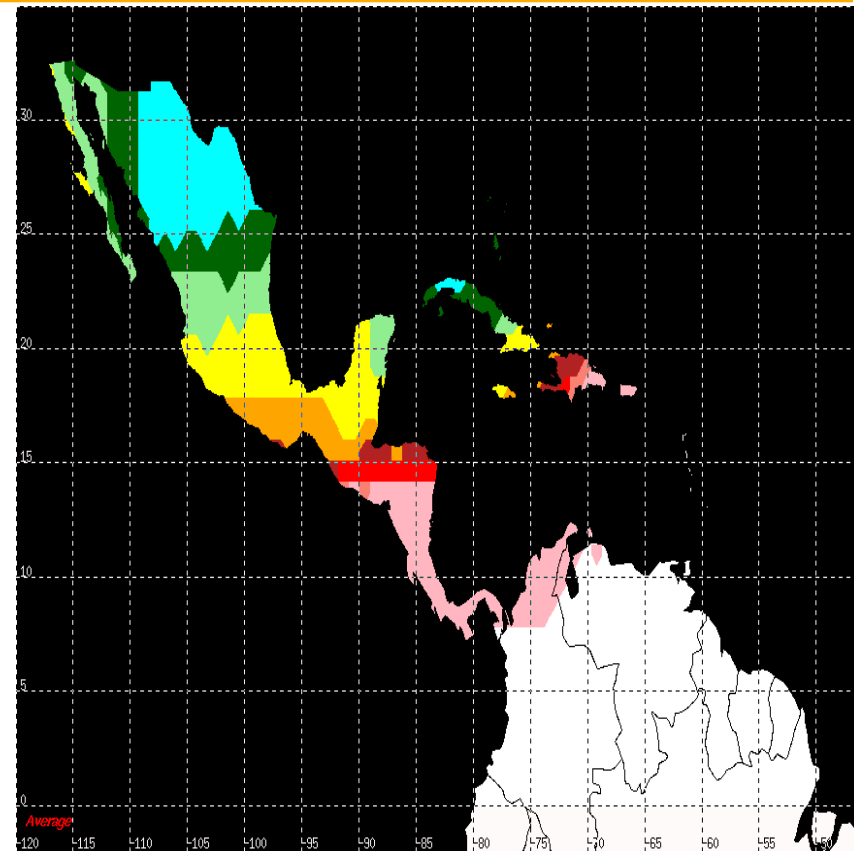




L5 Single-Frequency SBAS User Equipment Mode No Ionospheric Constraints Modeled



Without Scintillation



With 95th Percentile Scintillation





Acknowledgments

- **Ing. Deane Bunce of the U.S. FAA for sponsoring this work**
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