



CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

General Description of MITRE's Service Volume Models

The Atmosphere and its Effect on GNSS Systems

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Ing. Roland Lejeune



Overview

- **Need for Service Volume Model**
- **“Outage” and “Restoration”**
- **MITRE’s Simulation Models**
- **GPS Input to Simulation Models**
- **Satellite Failure and Restoration Rates**
- **Simulation Outputs**
- **Example availability maps**



Need for Service Volume Model

- **Accuracy, Availability and Continuity (A/A/C) of GNSS navigation services vary with satellite geometry**
 - The behavior of integrity monitoring functions also affects A/A/C performance
 - ABAS integration (e.g., with or without integrated inertial reference data)
 - SBAS integrity monitor designs
- **Computer models are important to estimate A/A/C performance**
 - To determine the desirability of potential changes
 - To support the generation of predictive NOTAMs
 - To estimate future performance

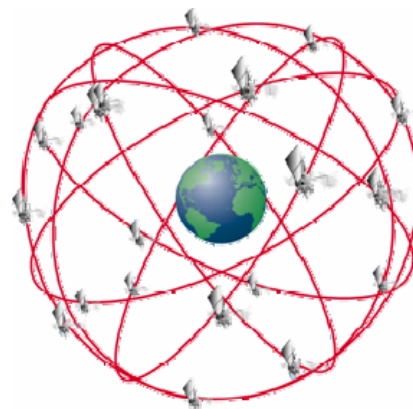


“Outage” and “Restoration”

Ground-Based NAVAIDS



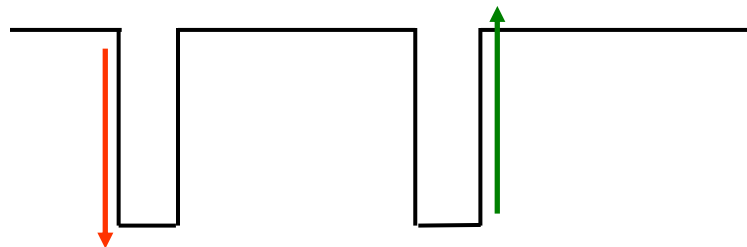
SATNAV



Restoration, e.g.:

- New satellite rises
- Satellite geometry improves
- Ionospheric event subsides

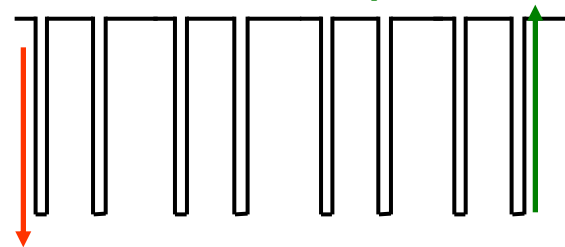
Repair Equipment



Ground Equipment Fails

“Up”

“Down”

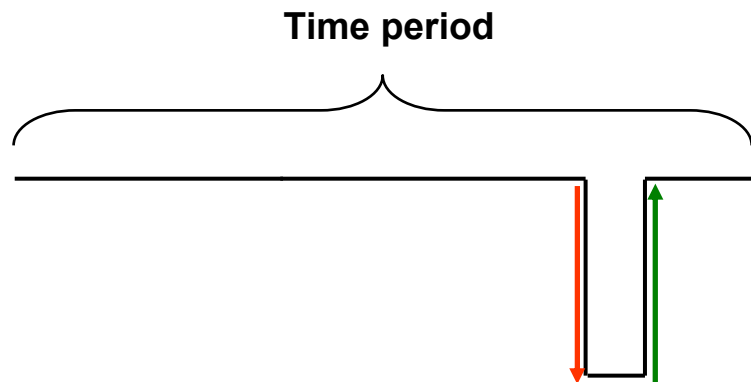


Outage Causes, e.g.:

- Satellites fail
- “Bad” satellite geometry (predictable)
- Ionospheric effects



Continuity and Availability



Continuity of service is the probability that service will stay “up” over a given time span (given that it was up at the beginning)

Often given as $1 - \text{continuity}$
(probability that the service will fail over a given time span)

Availability is the probability that the service is “up” if sampled at a random time (= ratio of up time to total time)

Impact of navigation service unavailability varies with application



MITRE's Simulation Models

1 of 2

- **MITRE/CAASD maintains four complementary computer simulation models for GNSS (GPS, GALILEO, ABAS, SBAS, GRAS, and GBAS) analyses**
 - **SBAS Worldwide Availability Tool (SWAT)**
 - **WAAS Analysis Testbed for Unavailability-of-Service Investigations (WATUSI)**
 - **GNSS Air Traffic Operations Model (GATOM)**
 - **Service Continuity Model (SCM)**
- **Main focus: availability of flight operations from en route through approach and landing**
- **Main output: prob{availability with integrity}**



MITRE's Simulation Models

2 of 2

- **Other outputs**
 - Accuracy
 - Continuity
 - Support for special analyses
- **The simulation models are not Monte Carlo models**
 - They compute service availability for all subsets of satellites in view, then factor in the probability associated with every subset



Different satellite input assumptions

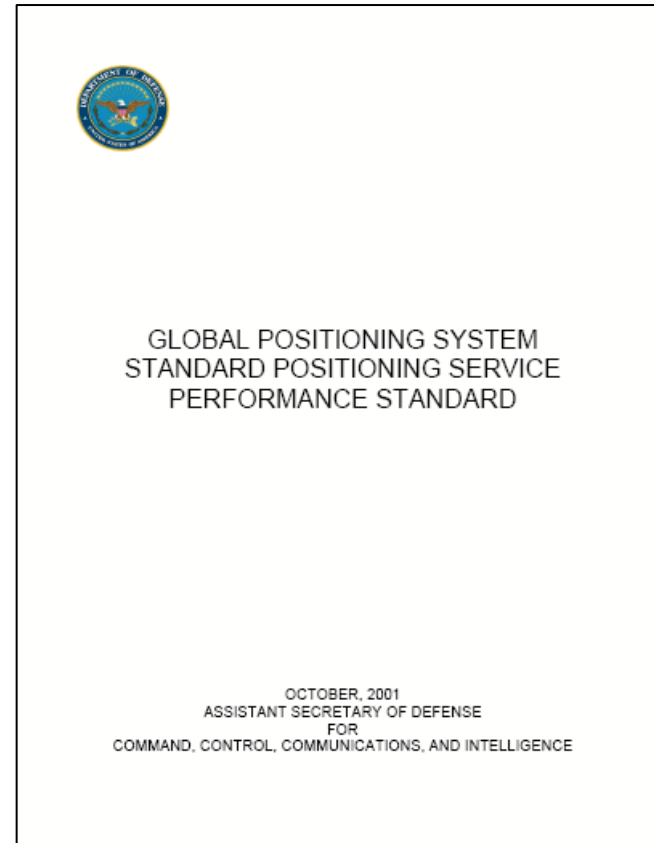
- **Stochastic (using IFOR)**
- **Deterministic failures**
- **Fixed/specified constellation**



Stochastic Inputs

- **Consistent with GPS SPS Performance Standard:**

“In support of the service availability standard, 24 operational satellites must be available on orbit with 0.95 probability (averaged over any day). At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and transmitting a navigation signal with 0.98 probability (yearly averaged).”





U.S. Interagency Forum on Operational Requirements (IFOR) GPS Constellation Assumptions

No. of Transmitting & Healthy Satellites in Primary Slots	Threshold Probability	Objective Probability
24 SVs	0.72	0.95
23 SVs	0.17	0.04
22 SVs	0.064	0.01
21 SVs	0.026	0.00
20 SVs	0.013	0.00
19 SVs	4.4×10^{-3}	0.00
18 SVs	2.6×10^{-3}	0.00

IFOR threshold probability assumptions are commonly used in availability modeling.



Stochastic Satellite Failure and Restoration Rates

- **MITRE's simulation models allow system designs to be evaluated under the minimum commitment from GPS SPS**
 - **Nominally 24 satellites with failure and restoration rates consistent with 21 satellites 98% of time**
 - **Designing for this case is an FAA requirement**



Deterministic Failure or Fixed/Specified Constellation Input

- **MITRE's simulations can also evaluate cases in which "n" out of "m" satellites are assumed failed**
 - We call this case "deterministic"
 - For each user location, the simulation computes the average availability over all n out of m cases
 - Of course, the case $n = 0$ corresponds to the "no failure case"
- **Finally, MITRE's simulations can provide results for any specified constellation**
 - The GPS constellation that existed on any particular day
 - A possible future GPS constellations with 27 SVs
 - The proposed GALILEO constellation

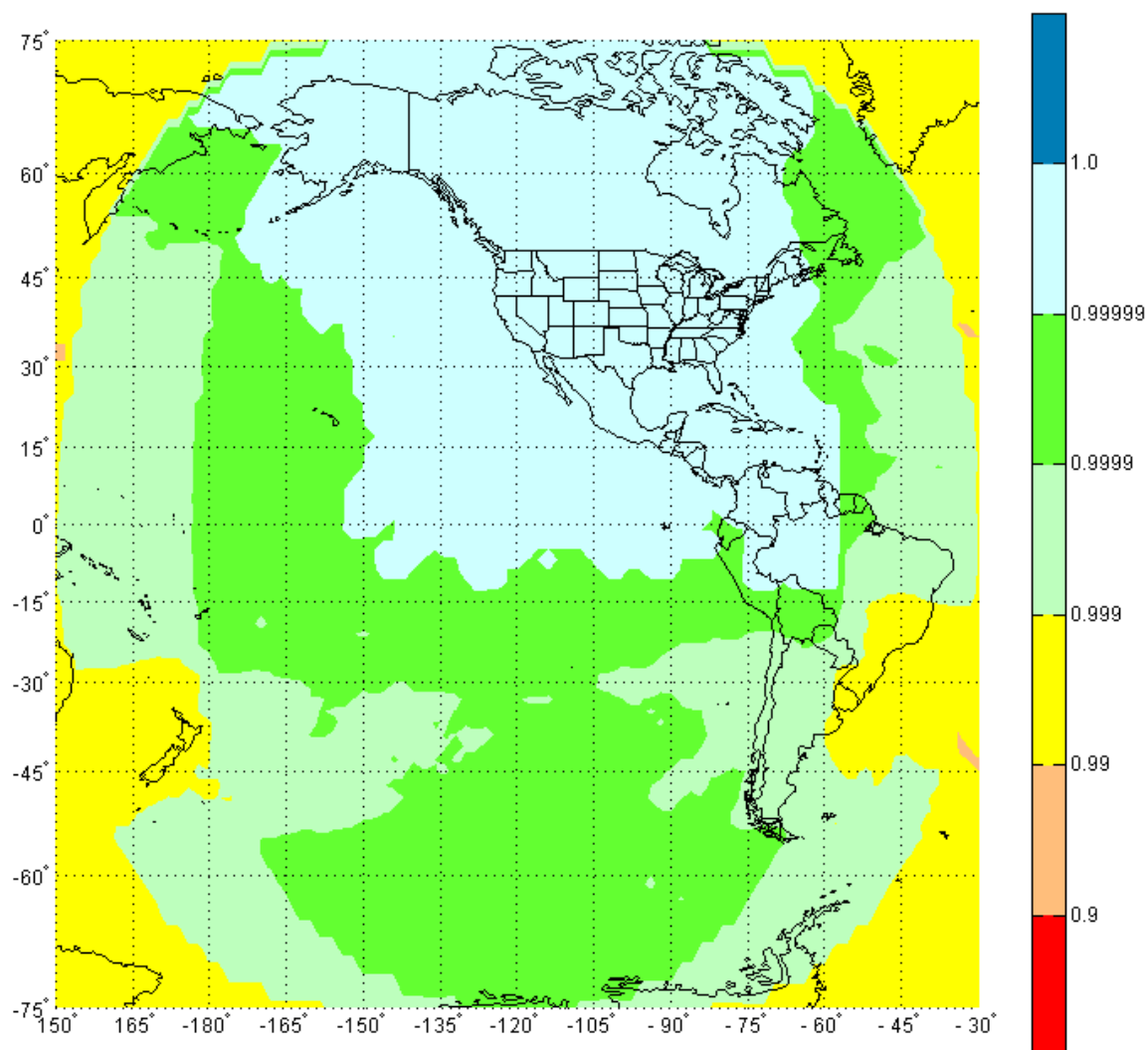


Simulation Outputs

- **In order to generate availability maps, calculations are done for a tight grid of user locations**
 - **Other outputs can be generated for more detailed studies also, e.g., availability as a function of time at specific airports**
- **In the case of SBAS, the computation accounts for the location of reference stations, the locations of geostationary satellites, the specific designs of the integrity monitor algorithms, error characteristics**
 - **Random failures of ground system components are normally not modeled**



Example 1: RNP 0.3 Availability using SBAS Receiver (Stochastic Failures)



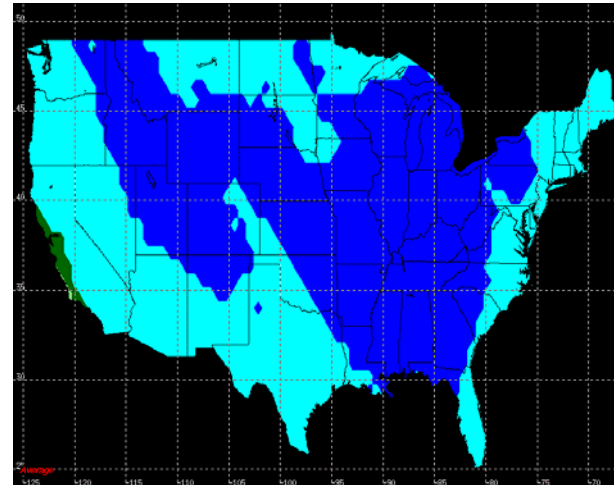
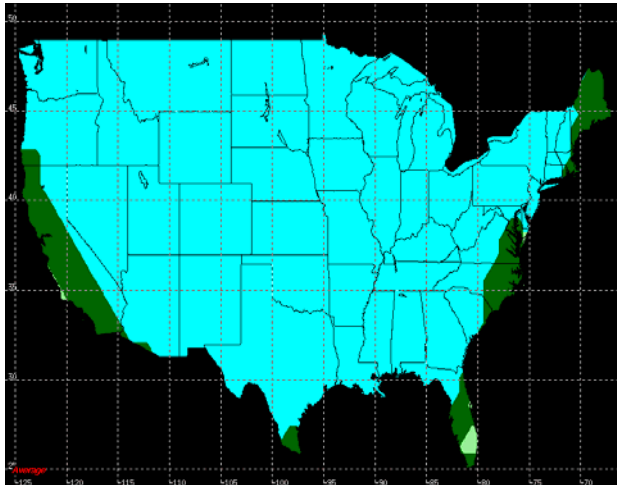


Example 2: WAAS LPV Availability from Release 6/7 to Release 8/9

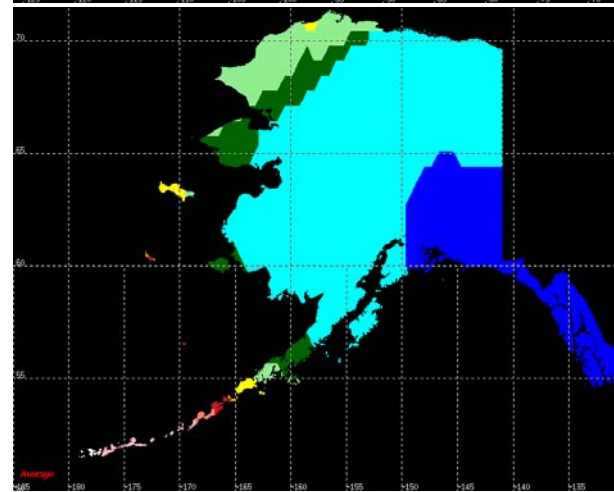
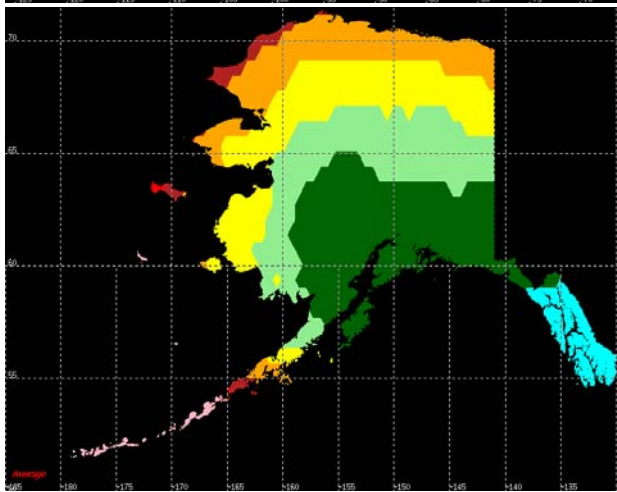
Release 6/7

Release 8/9.2

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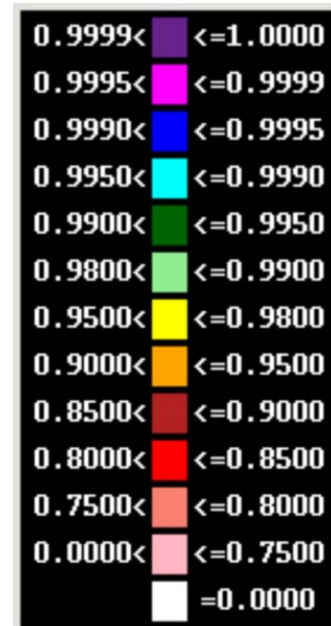


Satellite Reliability Models

- 24 nominal GPS w/ IFOR Threshold
- No GEO failures

GEOs Configuration

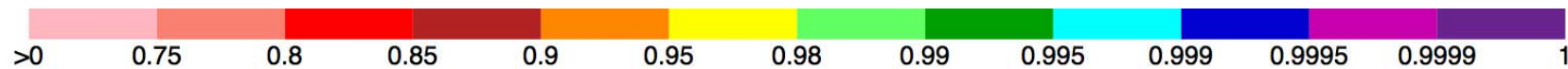
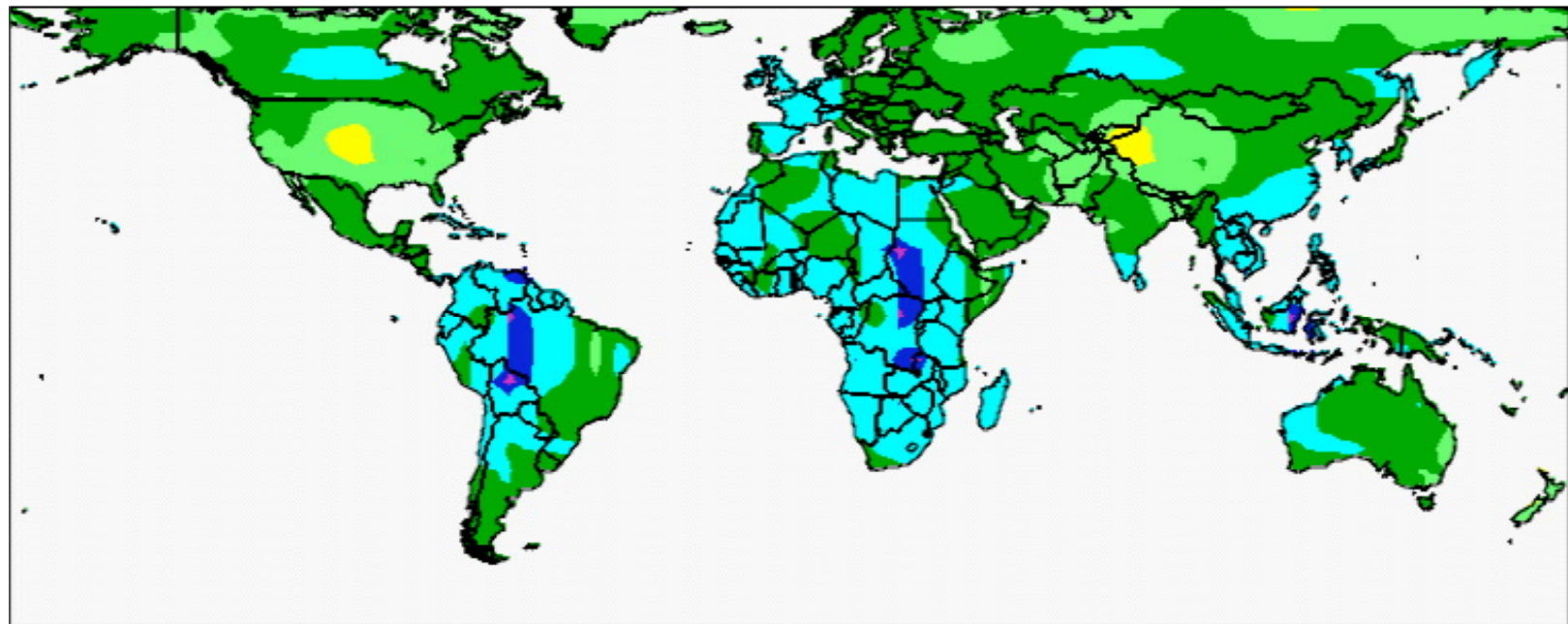
- R6/7 UDRE = 50 m for both GEOs
- R8/9.2 UDRE = 7.5 m for both GEOs



AVAILABILITY



Example 3: Worldwide LPV-200 Availability with GPS III



Assumptions: 27 satellite constellation with 1 failed (availability is averaged over all cases of 1 satellite out of 27 failed) and proposed new RAIM algorithm meeting LPV-200 requirements