SBAS DUAL-FREQUENCY MULTI-CONSTELLATION (DFMC) ANALYSIS WITH THE SBAS DFMC SERVICE VOLUME SOFTWARE PROTOTYPE (DSVP)

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CONTENT

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INTRODUCTION

INTERNATIONAL CONTEXT

GNSS capacity is growing fast with the development and improvement of new core components (DFMC scenario : **Dual-Frequency Multi-Constellation**)

- ICAO augmentations systems can benefit from those improvements
  - *SBAS evolution: SBAS Dual-Frequency Multi-Constellation*
  - *GBAS evolution: GAST-F Concept*
  - *ABAS evolution: Advanced Receiver Autonomous Integrity Monitoring (ARAIM)*

SBAS DFMC standardization is on-going

- Initial draft ICD (Interface Control Document) and Concept of Operation developed within IWG (International SBAS Service Provider working group)
- Receiver MOPS being developed by Eurocae WG62 and RTCA SC-159
- ICAO SARPs being developed

EUROPEAN CONTEXT

Development of the SBAS new generation is on-going: SBAS DFMC evolution in Europe will be introduced with **EGNOS V3**

- Study phase closed in early 2016
- Development phase to be launched end 2017
- SBAS DFMC operation with EGNOS V3 planned after GPS L5 FOC (around 2025)

The **consolidation of the new SBAS DFMC standard** is a critical milestone to ensure that:

- the European investment in the EGNOS V3 program will not be jeopardized
- EGNOS V3 will be interoperable and compatible with the future ICAO SBAS DFMC standard
- Project risks with EGNOS development will be properly managed with a mature/consolidated standard

CNES OBJECTIVES WITH SBAS DSVP TOOL

DSVP = DFMC Service Volume Prototype

The SBAS DSVP is a software prototype of future DFMC SBAS L5 systems for validation purposes in the frame of standardization activities

- ICAO SARPS
- EUROCAE/RTCA MOPS

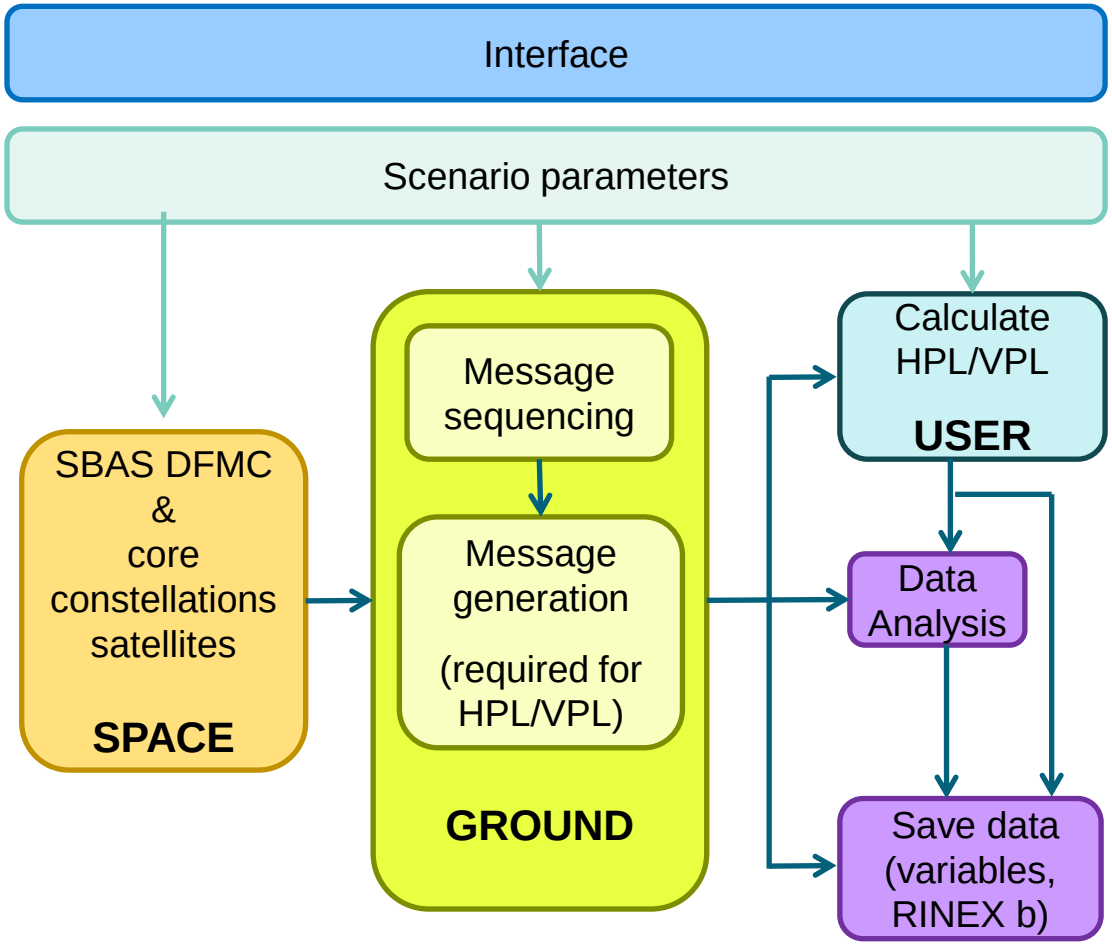
Evaluate system performances according to various operational contexts

Contribute to the SBAS DFMC standard consolidation

- Reviewing the on-going work of SBAS related working groups
- Disseminating the achievements of the project in SBAS related working groups

SBAS DSVP PRESENTATION

SBAS DSVP ARCHITECTURE



Modular Approach:

- Interface to ease operations
- Ground segment Module
- User segment Module

Global simulator including:

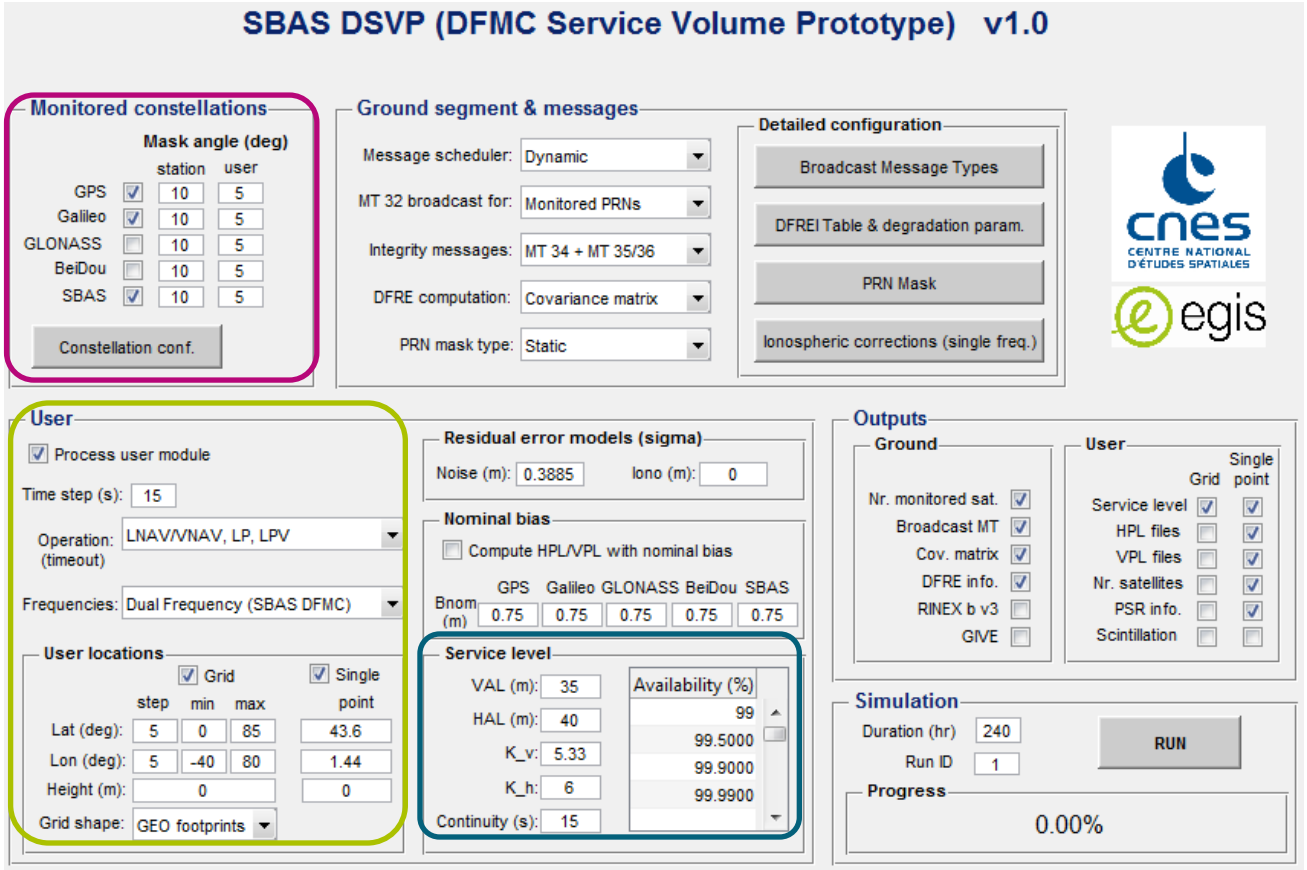
- Satellite emulator (core constellation and SBAS GEOs)
- Network of ground stations
- SBAS L5 message stream computation
- SBAS DFMC Protection level computation

SBAS DSVP INTERFACE & FUNCTIONALITIES (1/2)

Monitored constellations
- Orbit via almanac

User module
- Grid + single point location
- Capacity of single-frequency L5 mode (not in draft standard)

Configurable service level requirements

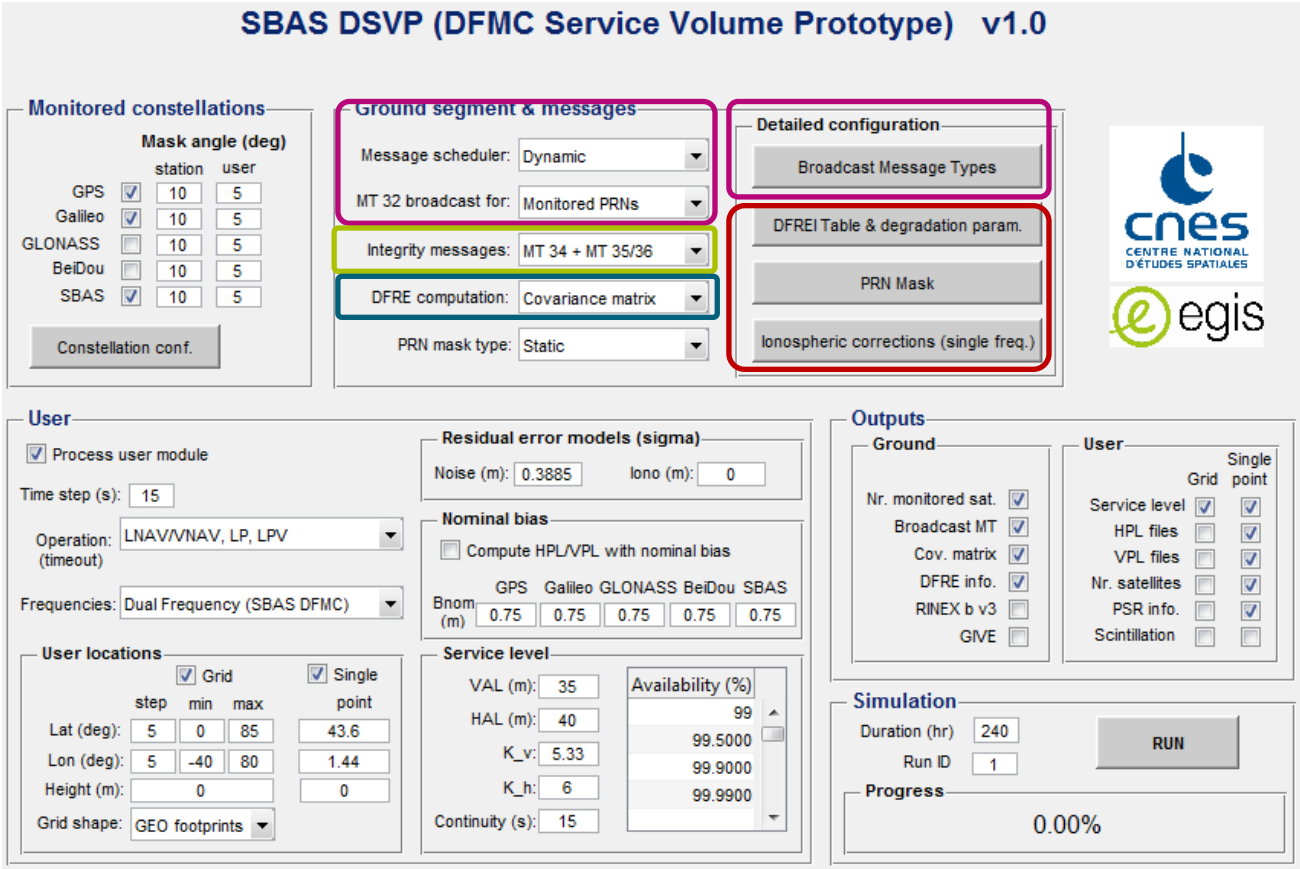


SBAS DSVP INTERFACE & FUNCTIONALITIES (2/2)

Message scheduler:
- Capacity to define new messages
- Dynamic or predefined order

Integrity messages:
- MT35 (+ MT36)
- MT34
- MT34 + MT35/36

DFRE estimated from relative positions satellite - ground stations



Configurable message contents: DFREI table, degradation params, PRN mask, etc.

SBAS DSVP OUTPUTS

SBAS Message analyses:

- Bandwidth occupation per message type
- Distribution of the time to first fix
- Observed update intervals per message type
- Number of satellites selected in the PRN mask monitored by the ground

SBAS correction analyses:

- Distribution of DFRE before discretisation and DFRE discretisation error
- Plots of sigma DFRE versus visible stations or GDOP

User service analyses:

- Availability maps for various alert limits
- VPL and HPL statistical maps
- Pseudorange error distribution at specific locations

ANALYSIS OF NUMBER OF MONITORED CONSTELLATONS

BROADCAST INTEGRITY INFORMATION (1/2)

SBAS DF integrity information (DFREI) must be broadcast at least every 6 sec for each monitored satellite

SBAS DFMC has two possible methods to broadcast integrity information :

- **Full DFREI** value:
  - *In **MT 35**, for the **first 53 satellite slots** selected in the PRN Mask*
  - *In **MT 36**, for the **last satellite slots** selected in the PRN Mask **starting from the 54***
  - *In MT 34, for only 7 satellite slots*
  - *In MT 32 or MT 40 for 1 satellite*
- **Relative** to a reference DFREI value, in **MT 34** via DFRECI **for all monitored satellites**:
  - *DFRECI: « DFREI not changed »*
  - *DFRECI: « DFREI increased by 1 »*

MT 34 is useful to update the DFREI of **more than 53 monitored satellites** in a single message

BROADCAST INTEGRITY INFORMATION (2/2)

Users need to store the correct reference DFREI to apply the relative DFRECIs broadcast in MT 34:

Epoch (s)	0	6	12	18
Parameters broadcast in MT 34	Full DFREI = 5	Full DFREI = 7	« DFREI not changed » (reference DFREI = 7)	« DFREI not changed » (reference DFREI = 7)
Parameters employed by User	Full DFREI = 5	**Message lost** Stored DFREI = **5**	« DFREI not changed » (reference DFREI = **5**)	« DFREI not changed » (reference DFREI = **5**)

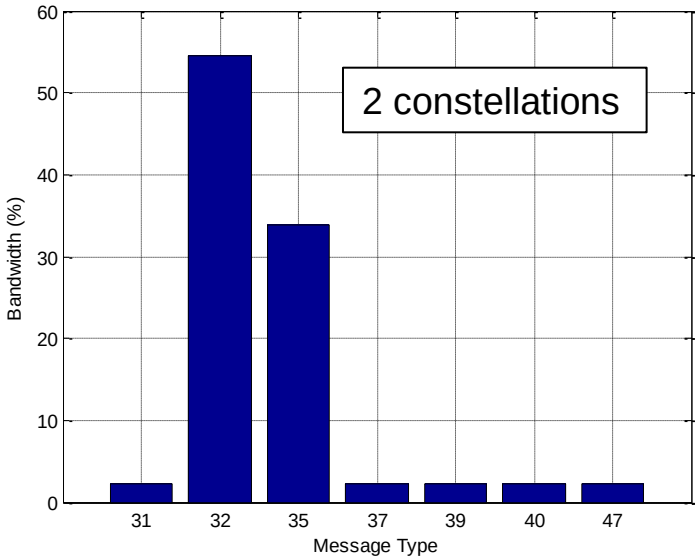
Strategy implemented in the SBAS DSVP prototype to assure correct reference DFREI at user level:

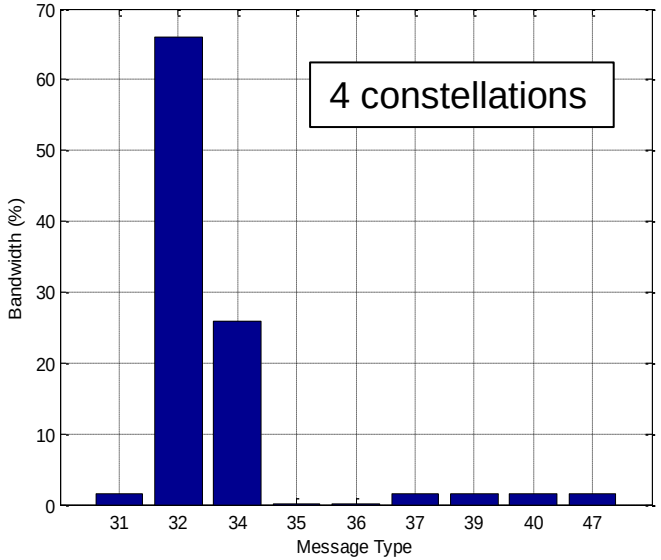
- The same **full DFREI** value must have been broadcast **minimum of number of times (3)** before starting to provide DFRECI information in relative mode for that satellite

SIMULATIONS CONFIGURATION

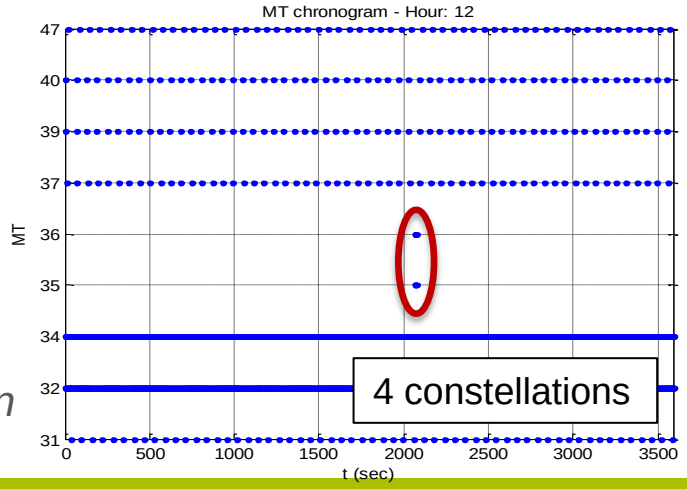
Dual-constellation case	Four-constellation case
53 SV selected in **PRN Mask** • GPS (27 SV) • Galileo (24 SV) • GEO (2 SV) (lon. 31.5°E and 5°E)	**92 SV** selected in **PRN Mask** • GPS (27 SV) • Galileo (24 SV) • GLONASS (23 SV) • BeiDou (16 SV) • GEO (2 SV) (lon. 31.5°E and 5°E)
Integrity Message: **MT 35**	Integrity Message: **MT 34** (with **MT 35 & MT 36** when required to maintain DFREI performance)
Duration: 10 days	
HAL = 10 m; VAL = 10 m	
Ground station network: same locations as current EGNOS RIMS	
Mask angle: ground stations = 10°; users = 5°	
DFREI >= 5	

SIMULATION RESULTS (1/2)

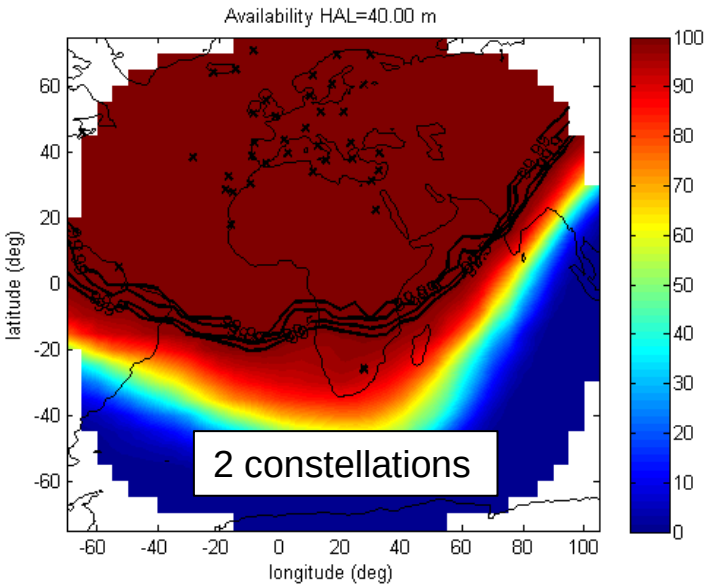


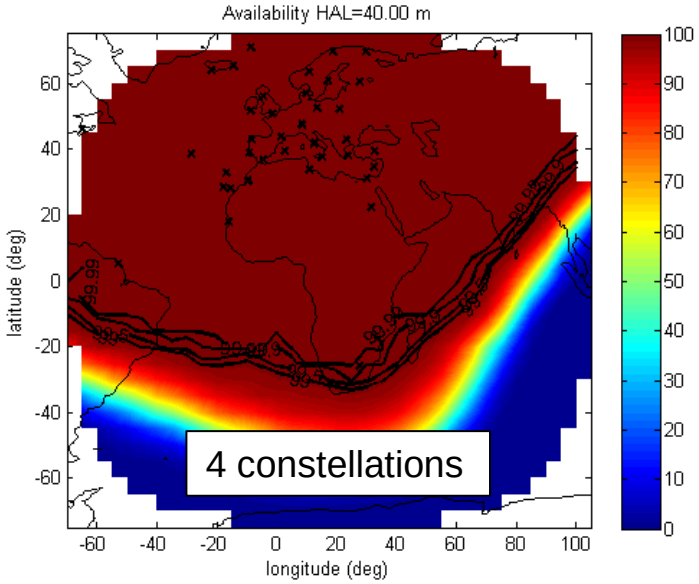


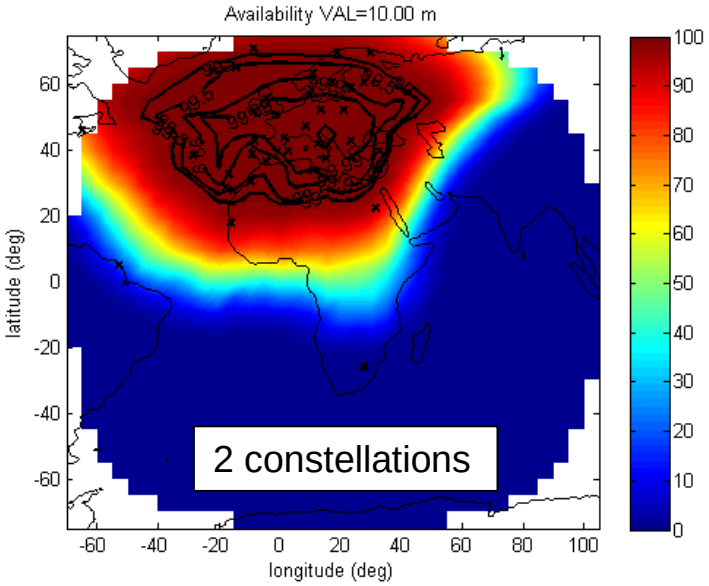
- All messages broadcast within the maximum update interval
- 4-constellation case: MT 35/36 broadcast at 22 epochs
  - *MT 35 & MT 36 needed to be broadcast at punctual epochs and not in a consecutive pattern*

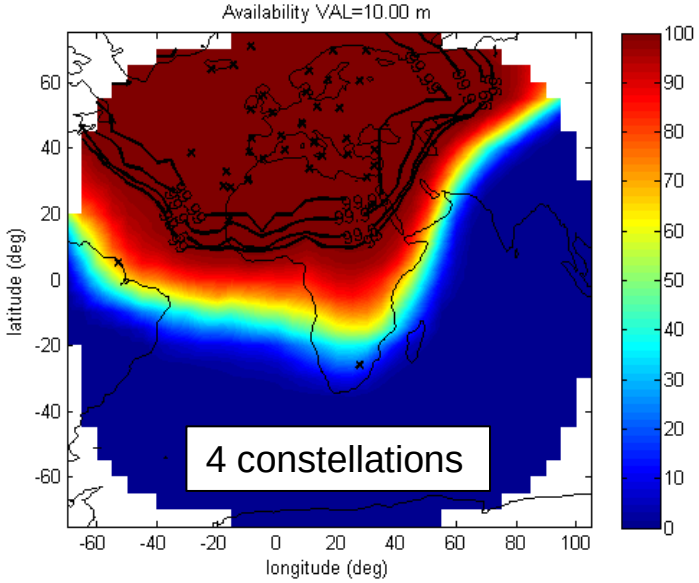


SIMULATION RESULTS (2/2)









ANALYSIS OF SINGLE-FREQUENCY SBAS L5 MODE

SINGLE-FREQUENCY SBAS L5

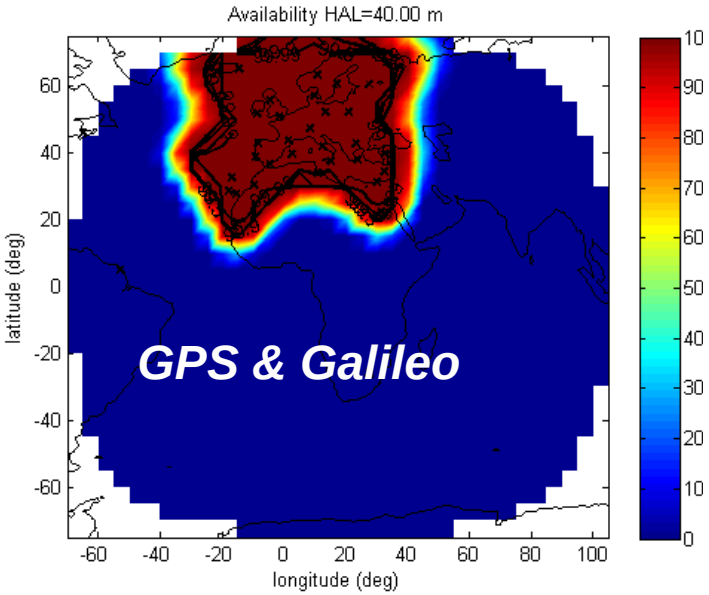
Single-frequency SBAS L5 mode not in current draft standards

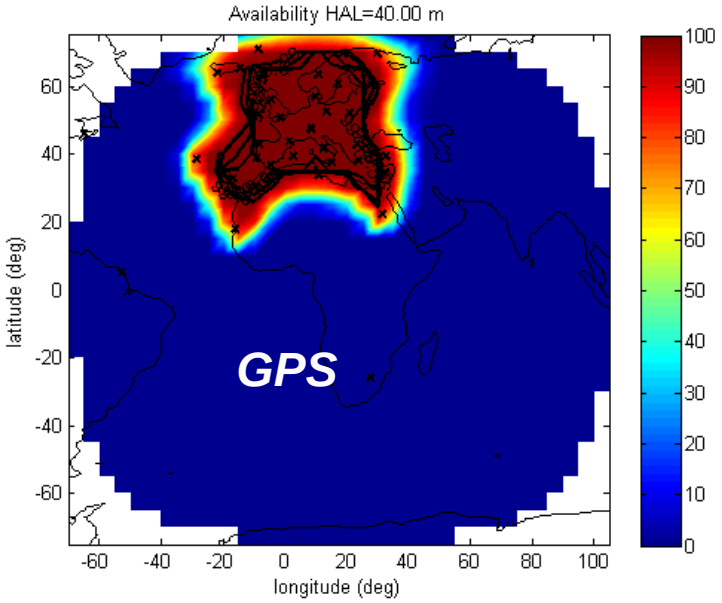
- *Analysis of the impact of the implementation of such mode*

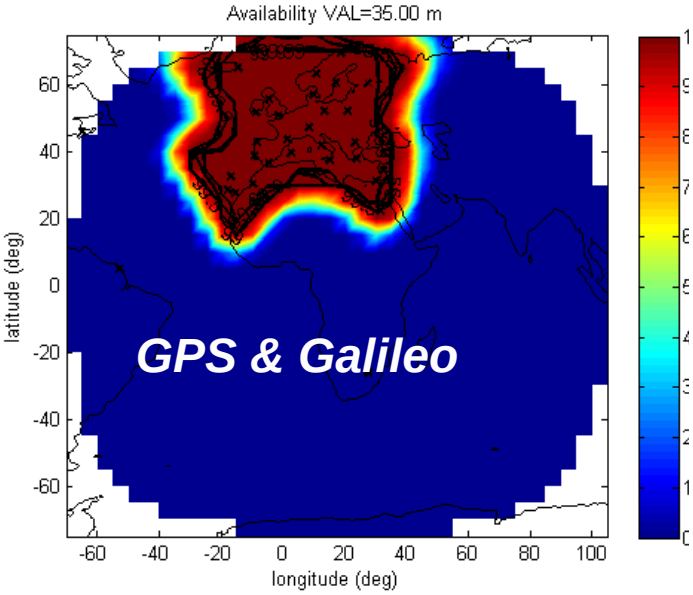
Simulation configuration
53 SV selected in PRN Mask : GPS (27 SV) + Galileo (24 SV) + GEO (2 SV)
Single-frequency SBAS L5 messages : • **MT 48** (IGP mask L5, equivalent to legacy SBAS L1 MT 18) – 5 messages   ○ IGP Mask equivalent to the one currently used in current EGNOS L1 • **MT 56** (Ionospheric corrections L5, equivalent to legacy SBAS L1 MT 26) – 20 messages • **MT 41** (Ionospheric degradation parameters) – 1 message
Integrity Message: **MT 35** // DFREI >= 5
Duration: 10 days // Mask angle: ground stations = 10°; users = 5°
HAL = 10 m; VAL = 35 m
Ground station network: same locations as current EGNOS RIMS

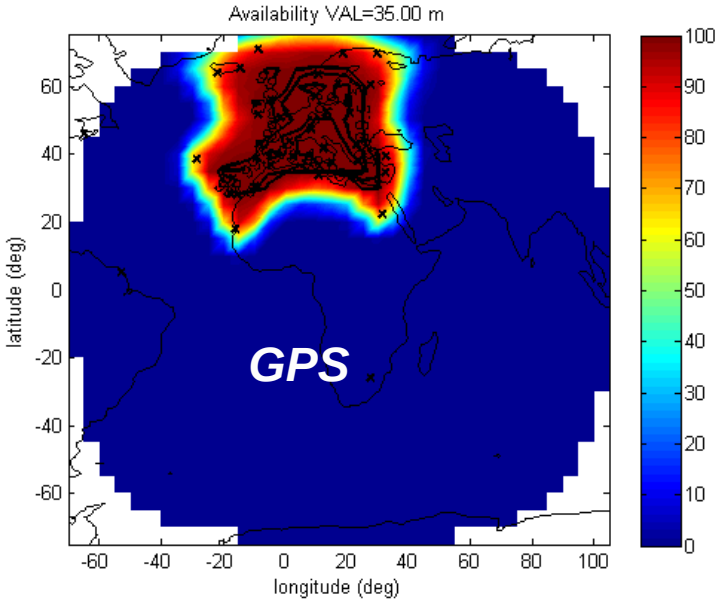
SINGLE-FREQUENCY SBAS L5 SIMULATION RESULTS

- Single-frequency SBAS L5 user:
  - *Availability HAL 40 m*
  - *Availability VAL 35 m*
- All messages were broadcast within their maximum update time requirements









ANALYSIS OF EQUATORIAL SCINTILLATION

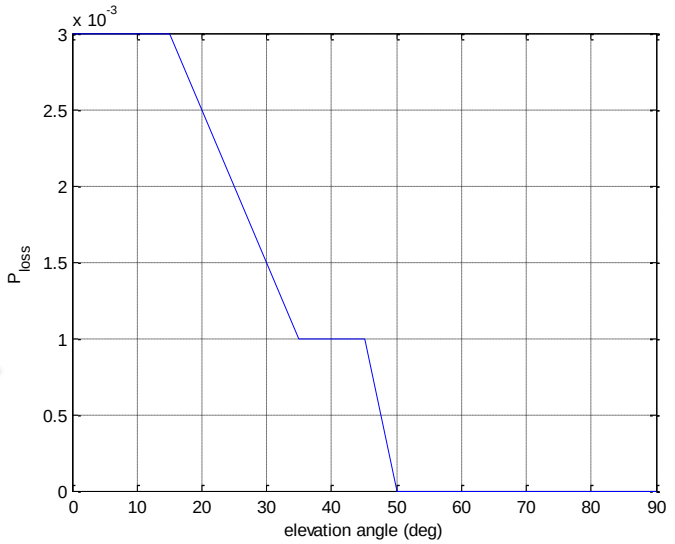
EQUATORIAL SCINTILLATION MODEL

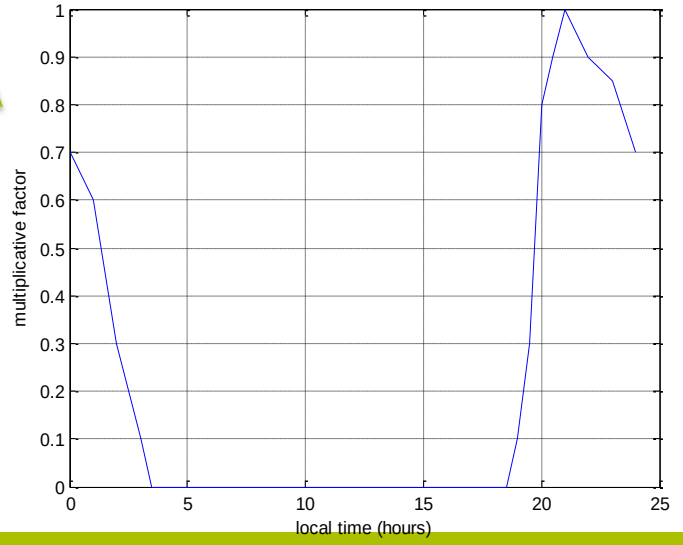
Equatorial scintillation model implemented in the prototype:

- Equatorial scintillation impact area
  - *upper and lower geomagnetic latitude*
    - Default values: [23.44°S, 23.44°N]
- Probability of loss of a user-satellite LOS with IPP inside the impact area
  - *P_loss function of the elevation angle*
- Local time factor
  - *multiplicative factor to P_loss as a function of the local time of the day*
- Duration of a loss (4 sec)
- Time interval to check loss (1 sec)

Simulations show no significant availability degradation due to equatorial scintillation for GPS & Galileo SBAS DFMC users

- HAL 40 m / VAL 10 m
- Current EGNOS RIMS network & GEOs





CONCLUSIONS AND WAY FORWARD

CONCLUSIONS

A SBAS DFMC Service Volume Prototype (DSVP) platform has been developed to support standardization activities

Some examples of preliminary but significant results have been presented:

- Analysis of **number of monitored constellations**
  - *Integrity messages: Users need to store the correct reference DFREI to apply the relative DFRECIs broadcast in MT 34*
    - in the prototype : broadcast full DFREI several times (3) before broadcasting relative DFRECI
  - *The system configuration with the maximum number of monitored satellites in the PRN Mask has been tested*

- Analysis of **equatorial scintillation**
  - *Model proposed function of elevation angle and local time of day*
  - *No significant impact on SBAS DFMC users over Europe*

- Analysis of a potential **single-frequency SBAS L5** backup mode
  - *Not in current draft standard*
  - *All messages broadcast within maximum update interval requirements (scenario GPS+Galileo)*

WAY FORWARD

- Formal validation of the prototype
- Add RINEX b outputs to be used as input for SBAS DFMC receiver prototypes
- Adapt user module to process RINEX b files containing SBAS DFMC messages
- Consolidation of the current work for the future SBAS L5 standard

THANK YOU FOR YOUR ATTENTION

BACK-UP SLIDES

EQUATORIAL SCINTILLATION SIMULATION RESULTS

SCINTILLATION MODEL – AVAILABILITY RESULTS

- No significant availability degradation due to equatorial scintillation
  - HAL 40 m
  - VAL 10 m
  - GPS & Galileo
  - EGNOS RIMS network
- Limited number of user locations impacted in Europe