

# Advanced RAIM Demonstrator

## ARTEX project

# OUTLINE

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  - **ARAIM Demonstrator**
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  - **Contribution to Galileo Safety of Life Working Group (GOSOL) and EU-US Working Group C (WGC)**
  - **ISMG ADD and ICAO Guidance Material**
  - **Contribution to MOPS**

# ARAIM CONTEXT AND BACKGROUND

## ARAIM INTERNATIONAL CONTEXT

- Development and improvement of the various GNSS Systems is an enabler for Aviation operations
- ICAO foresees evolutions of the current Navigation Systems, taking advantage of the **Multi-Constellation** environment with **Dual-Frequency** signals, for SBAS (Satellite-Based Augmentation System) as well as for ABAS
  - For ABAS, the evolution is the **Advanced RAIM** (ARAIM).
- Why ARAIM?
  - enable aviation safety of life operations, approaches with vertical guidance (LPV200)
  - Global coverage; support Arctic navigation
  - Redundancy in areas served by SBAS

For Galileo, ARAIM represents a **Strategic** opportunity

- Dual frequency (E1, E5a) is a key feature for ARAIM and Galileo will provide Full Operational Capability with dual frequency before GPS

⇒ **Galileo can take the lead!!**



# ARAIM INTERNATIONAL CONTEXT



- Standardisation work ongoing
  - ARAIM included in **ICAO** Navigation System Panel (NSP) initial version of the **Concept of Operations (CONOPS)** for Next Generation GNSS
  - **EUROCAE(EU) and RTCA(US)** include ARAIM for the preparation of new SBAS DFMC MOPS (Minimum Operational Performance Standards)
- Concept Definition
  - **EU/US WG-C** SubGroup has developed since 2010 the ARAIM concept
    - First Interim Report (2013), Milestone II (2015) and III (2016) Reports published<sup>5</sup> (available at EC and GPS websites)
  - Derived expected **Performance both for global Horizontal and Vertical Navigation** (target LPV 200, enabling precision approach)
  - Implementation **Roadmap with incremental steps**, starting with the Horizontal ARAIM

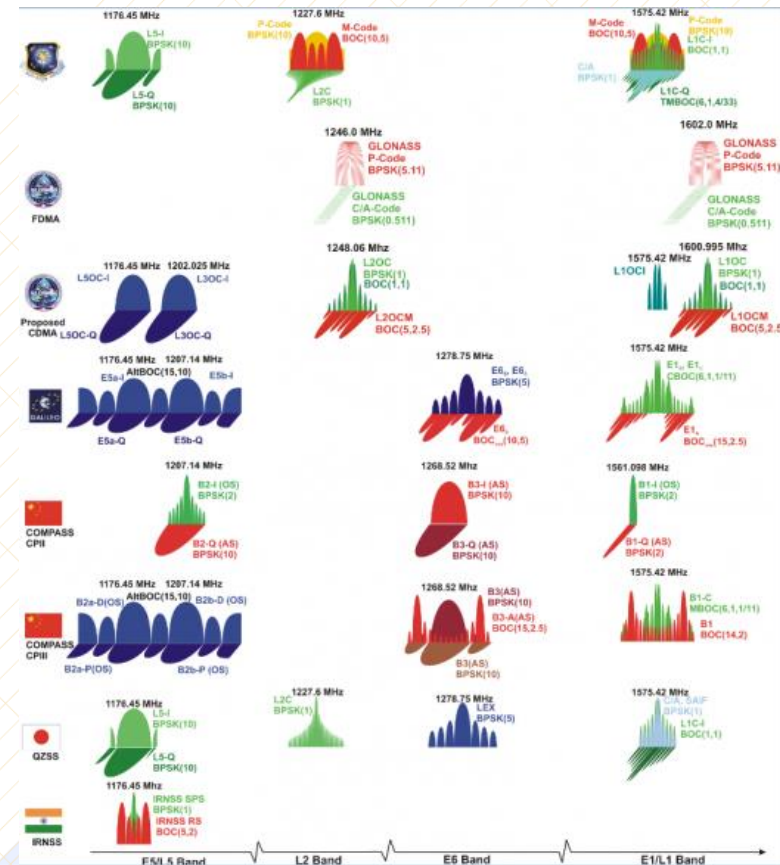
# ARAIM WITHIN THE GALILEO PROGRAMME



- ARAIM and EGNOS V3 formally part of Galileo mission for G2G, as **Open Service Contribution to Safety Of Life Applications**
- Following Galileo System D-CDR, a dedicated **Workplan (GO-SOL)** was set up in 2016
- Participated by **EC, ESA, EUSPA**, with Industry support
  - 8 formal Reviews conducted
  - Architecture and Signal definition Key Points
  - Mission Requirements derived to support EGNOS and H-ARAIM

# ARAIM CONCEPT BACKGROUND

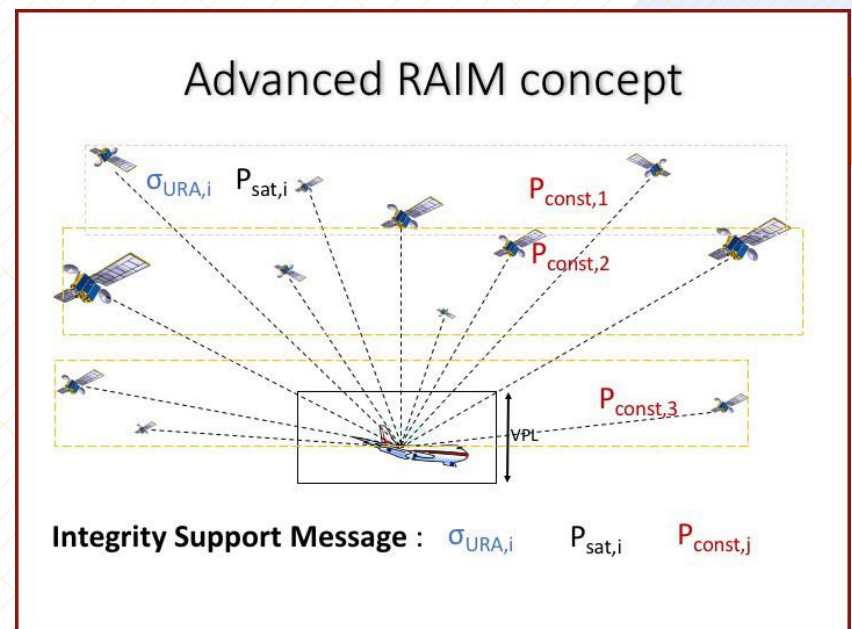
- Advanced RAIM (ARAIM) is an evolution of the Receiver Autonomous Integrity Monitoring (RAIM)
- RAIM is based on **redundancy of GNSS measurements** but only for single satellite failures
- In multi-constellation and multi-frequency scenario, receivers need to take into account **multiple failures and constellation faults**
- The use of **two frequencies** allows to significantly reduce the ionosphere error
- ARAIM addresses more **demanding operations** than RAIM (LPV-200, RNP-0.1, RNP 0.3)
- Service with **worldwide coverage**
- Relies on **commitments from the Constellation Service Providers**



# ARAIM CONCEPT BACKGROUND

- ARAIM is developed with evolutionary path: first horizontal service (**H-ARAIM**) addresses less demanding operations, and then vertical (**V-ARAIM**) for the most demanding one like, LPV-200
- The user exploits in the algorithm integrity information on the satellites: the **ranging error bounding** (User Ranging Accuracy), **error biases** (Nominal Bias), **satellites and constellation fault probabilities** ( $P_{sat}$ ,  $P_{const}$ )

- This information is included as commitment in the Aviation International Standards (SARPS)



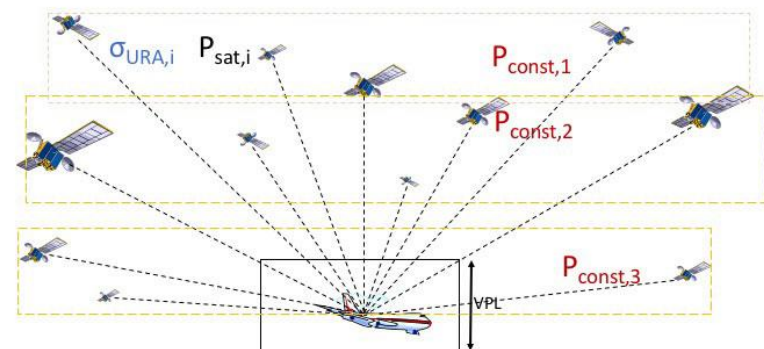


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- An Integrity Support Message (ISM) containing the integrity parameters is also broadcast.
- ISM allows for enhanced performance assessed over time
- ISM supporting H-ARAIM will be updated not on a frequent basis

## Advanced RAIM concept



Integrity Support Message :  $\sigma_{URA,i}$   $P_{sat,i}$   $P_{const,j}$

# USER ALGORITHM AND INTEGRITY SUPPORT MESSAGE



- The user algorithm developed by WG-C has been described in the **ARAIM Algorithm Description Document** which was provided to the community as guidelines for receiver prototyping and for standardization activities
- EUROCAE and RTCA develop receiver standards in particular **Dual Frequency Multi-constellation Multifrequency Minimum Operational Performance Standard (DFMC MOPS)**. The most recent versions include ARAIM together with SBAS DFMC services

# ARTEX PROJECT - INTRODUCTION

# ARAIM AND ARTEX PROJECT



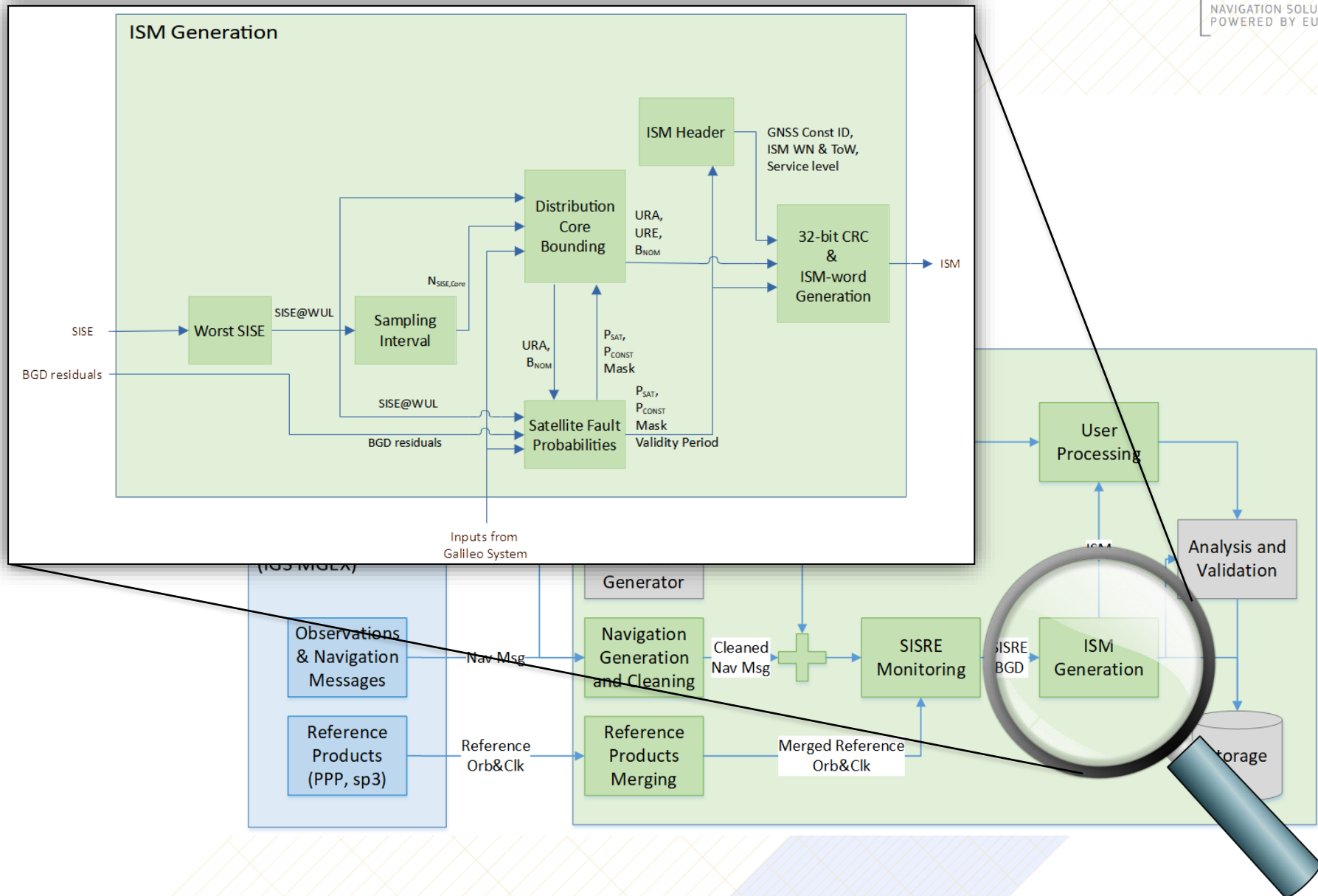
- First **project ADAM** started in 2016
  - Main objective was to develop an ARAIM demonstrator to support proof of concept
  - Developed the first version of the ARAIM Concept of Operations (CONOPS), later adopted by WGC
  - Project was terminated in March 2019 after completing ~50% of the overall tasks. Arrangements made with the Joint Research Centre (JRC)<sup>1</sup> and EC-DEFIS to continue the activities.
- The project **ARAIM for Testing and Experimentation (ARTEX)** was then started in 2019 to complete ADAM tasks and support standardization activities
  - Development of a demonstrator for the ISM generation
  - Execution of experimentation on user, ISMG and Galileo design aspects
  - Formulate recommendation for the standardization activities
  - Contribute to development of International Standard on ARAIM

<sup>1</sup> The Joint Research Centre (JRC) is the European Commission's science and knowledge service which performs research activities supporting EU policies, as technical officer and technical expert.



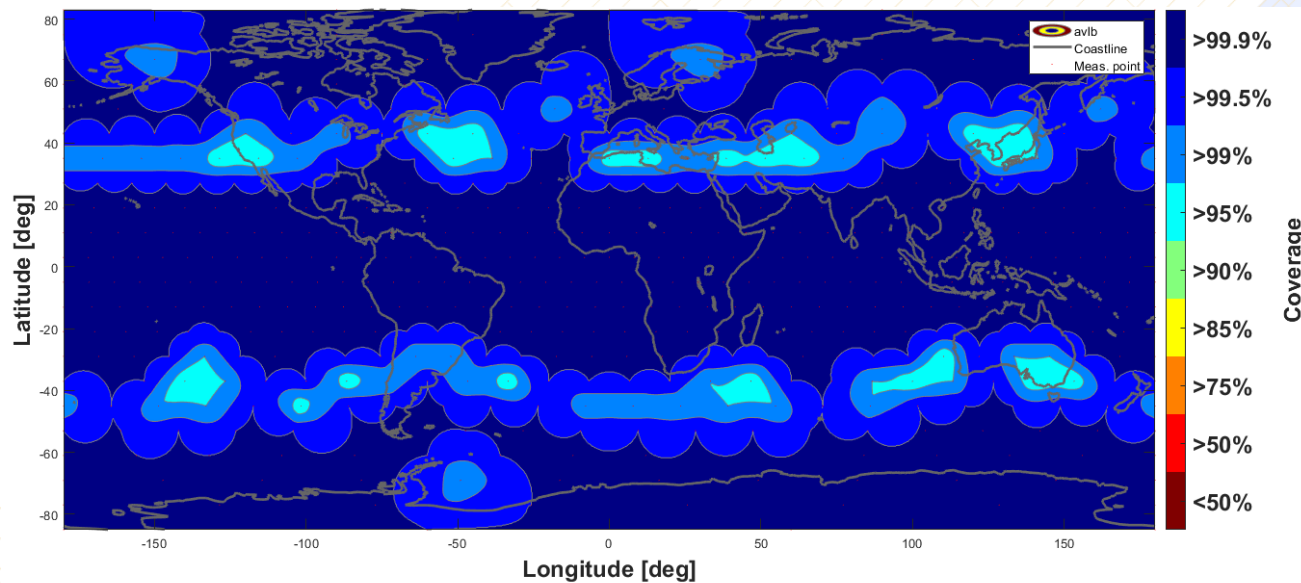
# ARTEX PROJECT - ARAIM DEMONSTRATOR

# ARAIM DEMONSTRATOR ARCHITECTURE



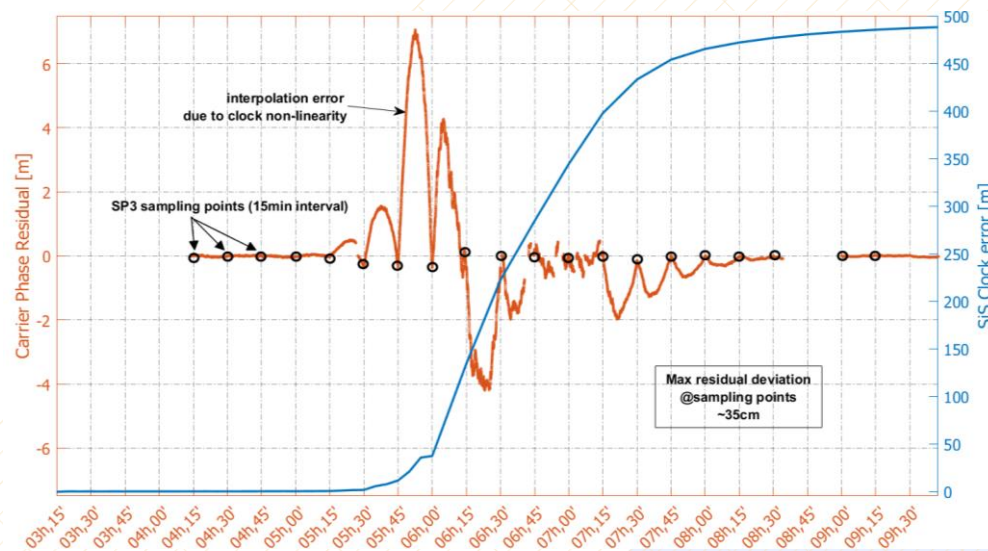
# ARAIM DEMONSTRATOR KEY ELEMENTS

- **GNSS monitoring** for Galileo, GPS, Beidou
- Orbit, Clock and satellite group delay analysis using more than 160 stations from **IGS MGEX network**
- Implementation of **User Algorithm based on ADD v3.1 and latest updates**
  - Cross-checked with Stanford MAAST implementation
  - Used to run sensitivity analysis on ISM parameters and integrity margins



# ARAIM DEMONSTRATOR KEY ELEMENTS

- Offline ISM generation including:
  - Several ranging error **bounding methodologies**
  - Assessment of **error time correlation**
  - **Sensitivity analysis** capability by comparing several years of data in an automatic and autonomous process
  - **Monitoring based on phase measurements** and PPP processing (see figure with Galileo fault on 6<sup>th</sup> June 2017)

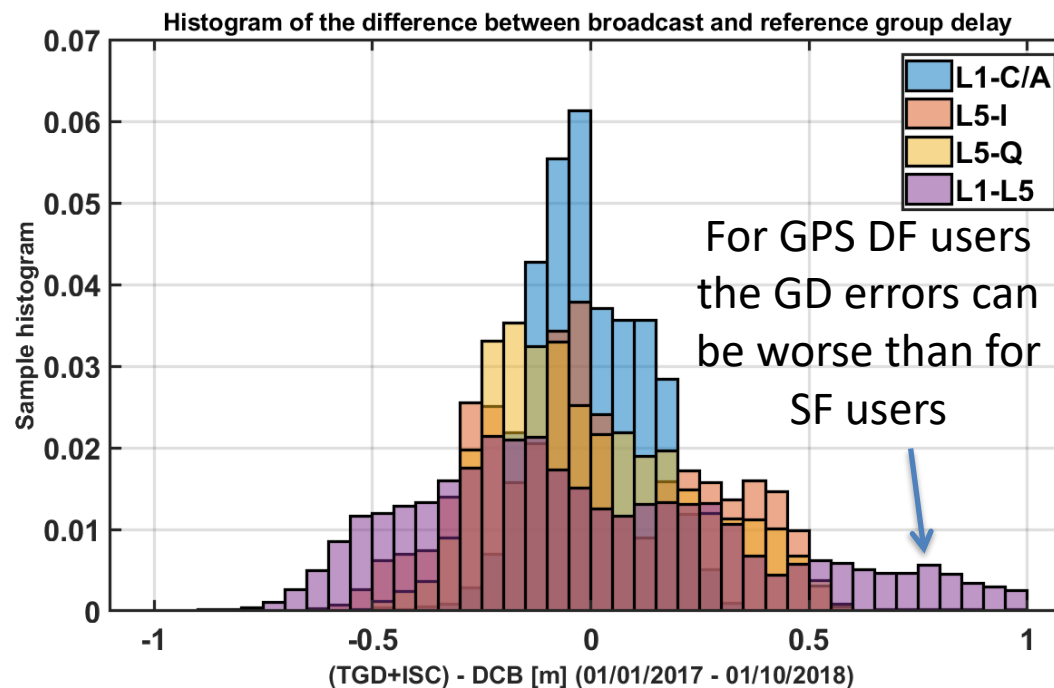




# ARTEX PROJECT - EXPERIMENTATION ACTIVITIES

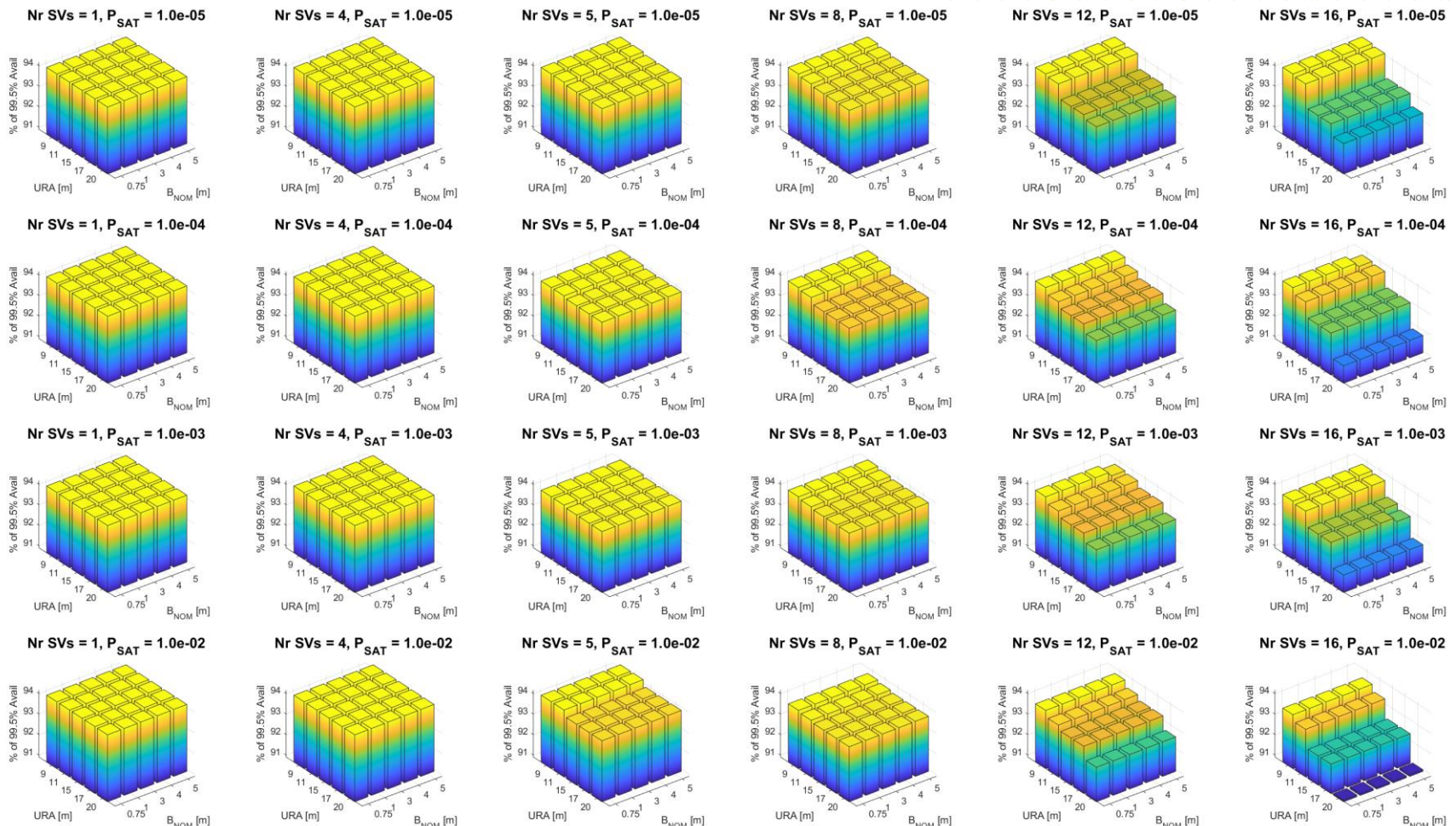
# DEVELOPMENT OF GALILEO GROUP DELAY MODEL

- ARAIM Single Frequency users require modelling and bounding of satellite Group Delays (GD)
- For Galileo an ad-hoc model was developed which exploits the differences and advantages of Galileo with respect to other constellations



# EXPERIMENTATION ON GROUPING OF SVS IN THE ISM

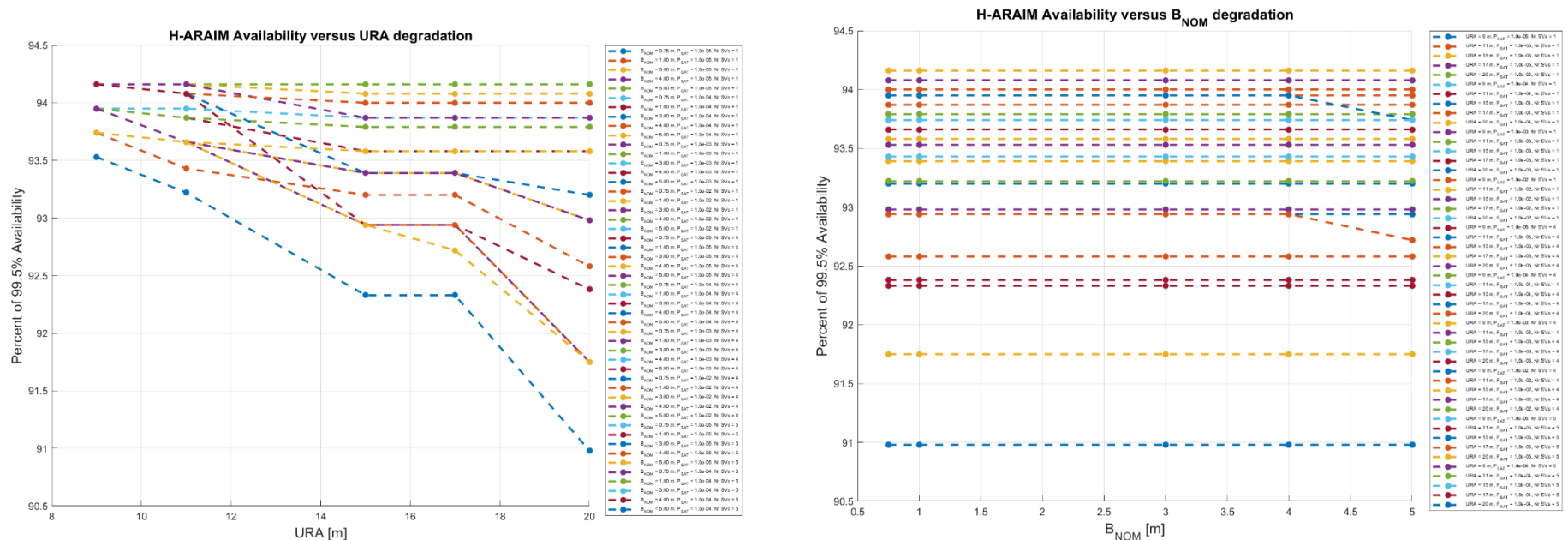
- Sensitivity analysis over Integrity parameters to assess the optimum number of satellites to be grouped in the ISM





# ISM PARAMETER MOST IMPACTING USER PERFORMANCE

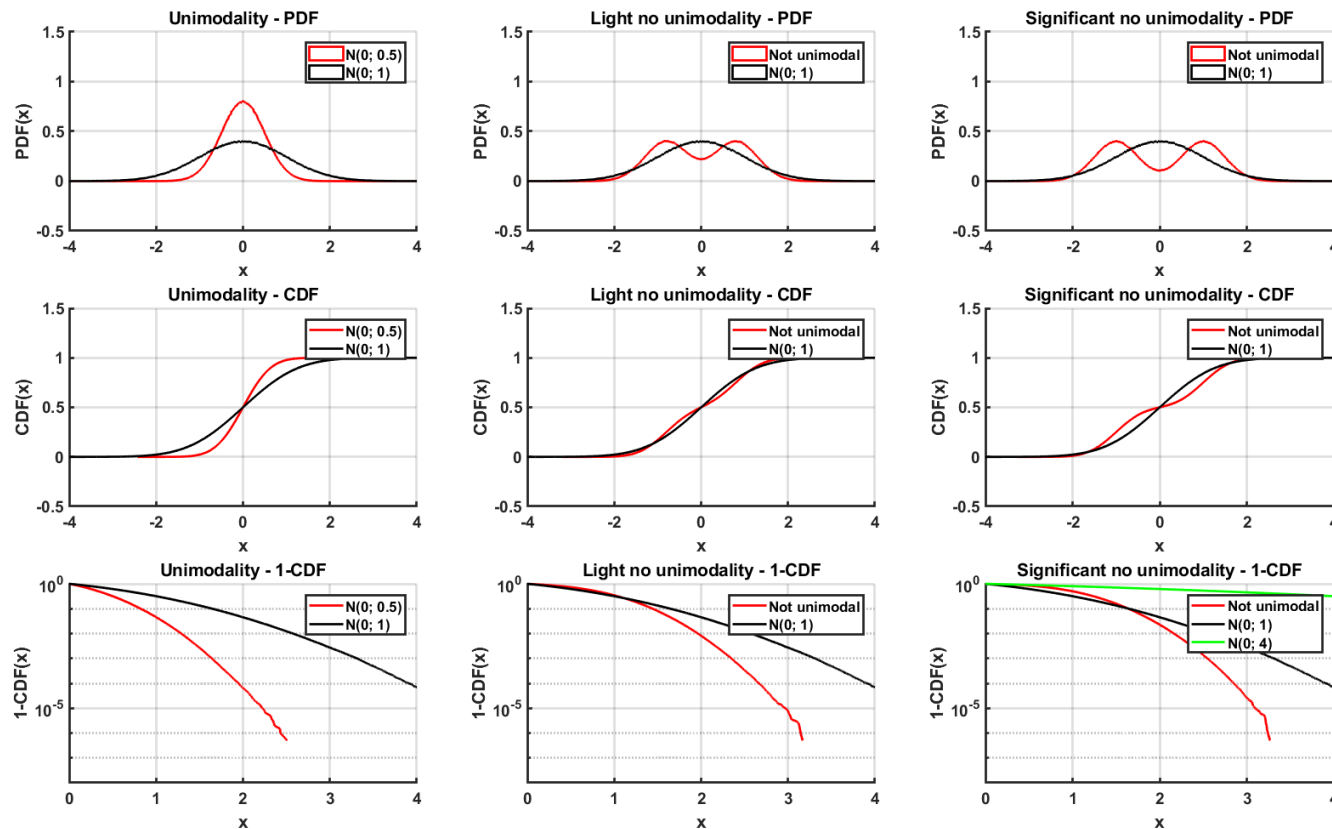
- User availability is most **sensitive to URA degradation**.  $B_{NOM}$  is preferably increased with respect to URA,  $P_{SAT}$  and  $P_{CONST}$
- **Maximum values for each ISM parameters** were derived from a sensitivity analysis of the availability performance to decide when a satellite shall be flagged as “not to be used for H-ARAIM”





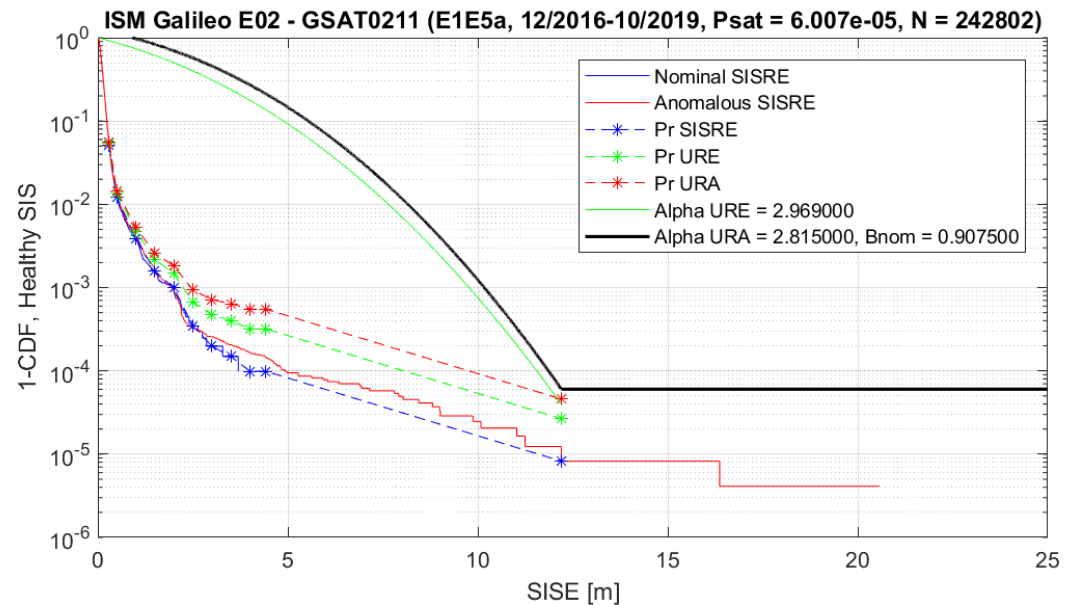
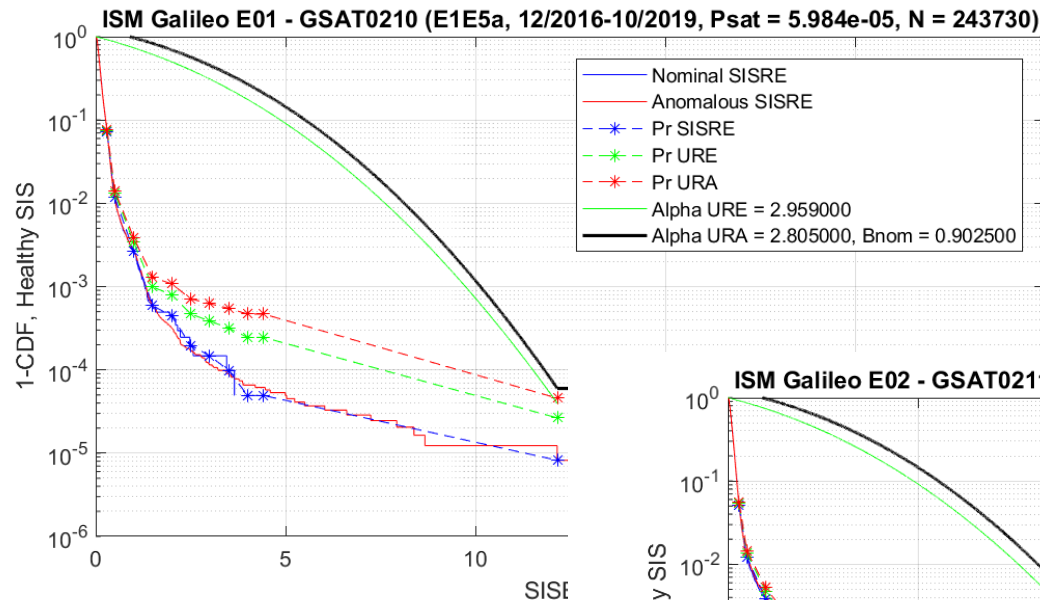
# RANGING ERROR BOUNDING METHOD

- Development of a methodology to proper tune ISM parameters and provide a **bounding method robust to convolution** and transformation from ranging to position domain



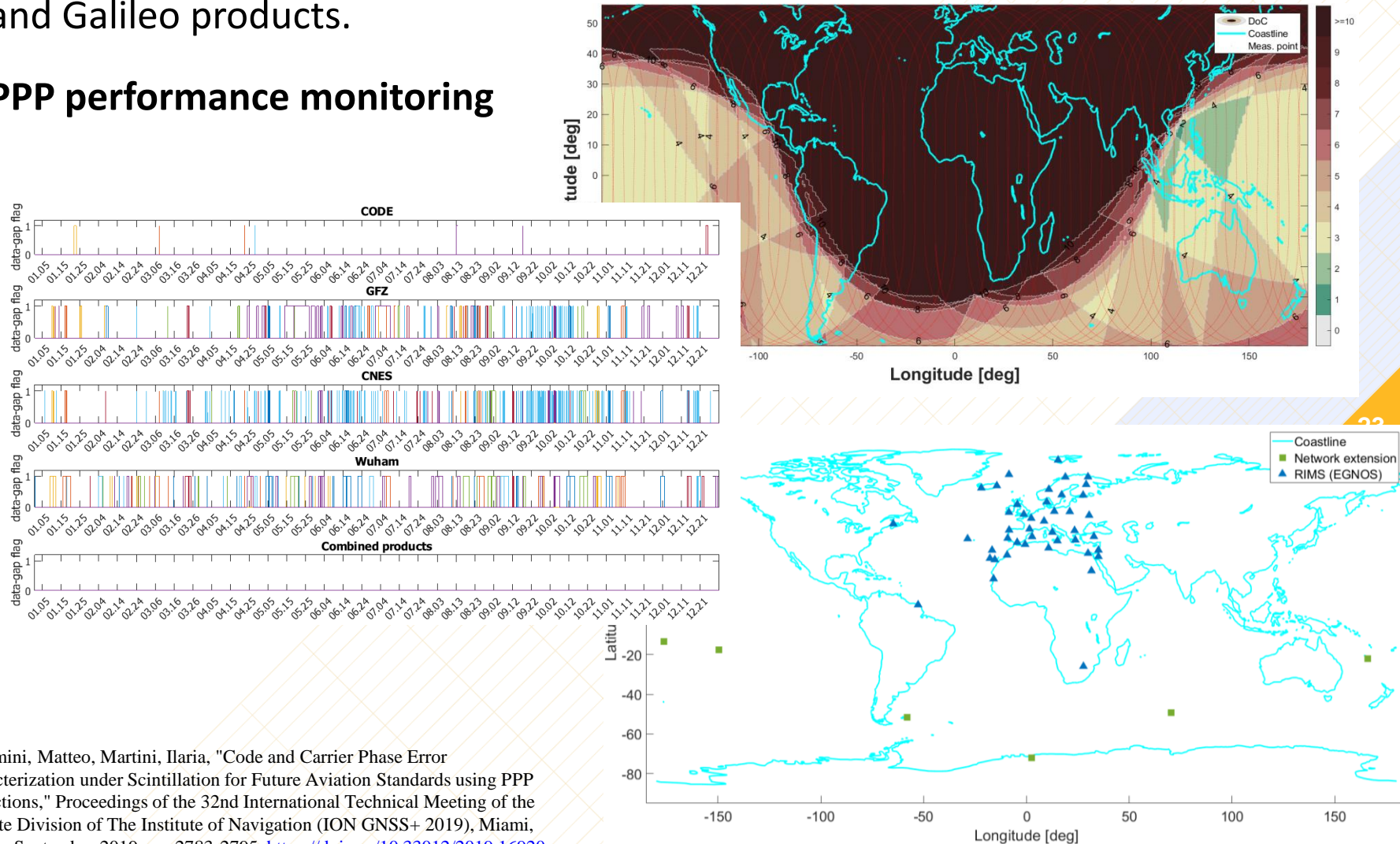
# GENERATION OF ISM FOR GALILEO WITH REAL DATA

- Processing of 4 years of Galileo service history and generation of the ISM parameters for Galileo satellites



# STUDY OF ISMG MONITORING NETWORK AND DATA GAPS

- ISMG network design and reduction of data-gap after cleaning and merging GPS and Galileo products.
- PPP performance monitoring

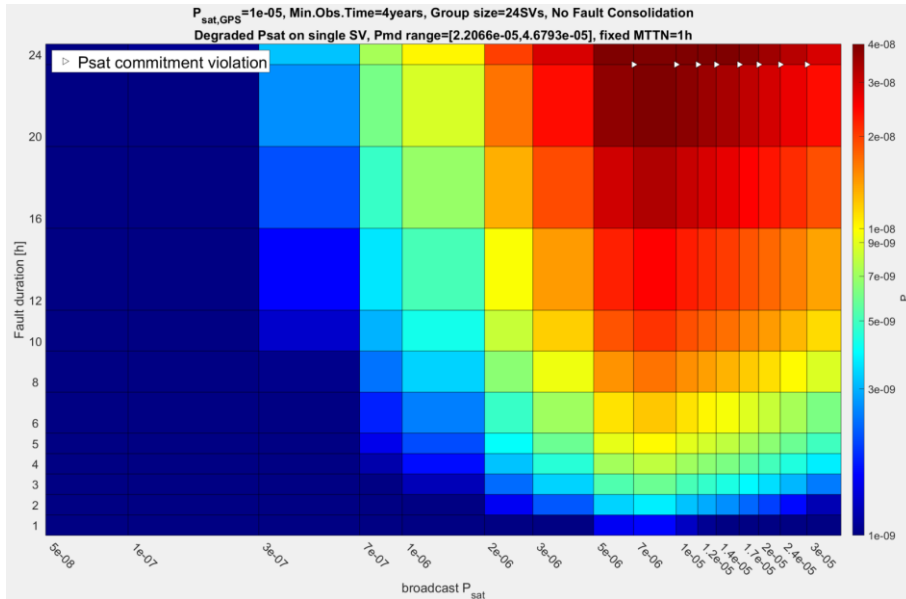


Sgammini, Matteo, Martini, Ilaria, "Code and Carrier Phase Error Characterization under Scintillation for Future Aviation Standards using PPP Corrections," Proceedings of the 32nd International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2019), Miami, Florida, September 2019, pp. 2783-2795. <https://doi.org/10.33012/2019.16920>

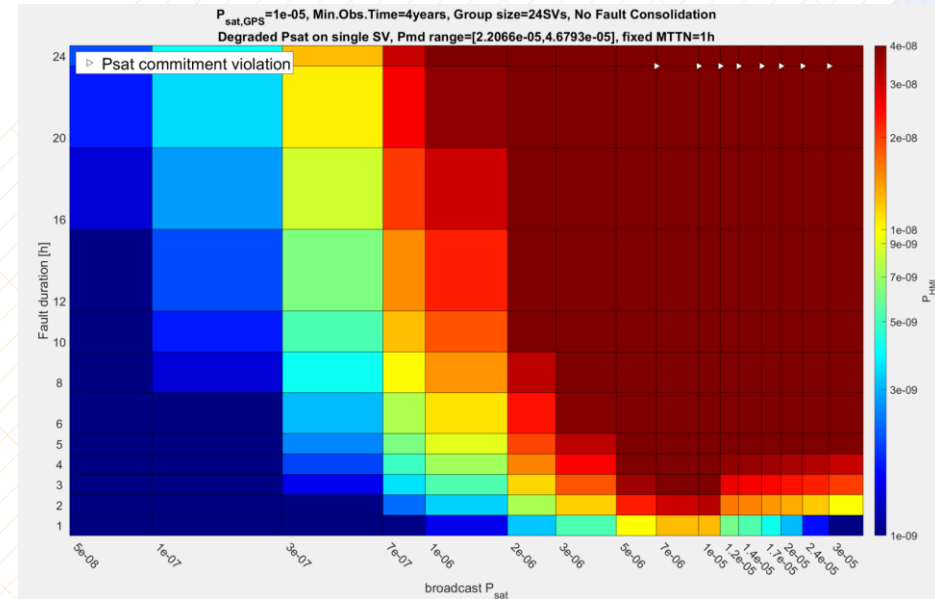
# IMPACT OF OPTIMISTIC ISM ON ARAIM USERS

- Support the ARAIM safety case analysis assessing **maximum duration of a wrong ISM** which is tolerable by the user

$P_{HMI}$  contribution of Monitored  
( $2.2e-5 < P_{md} < 4.7e-5$ )



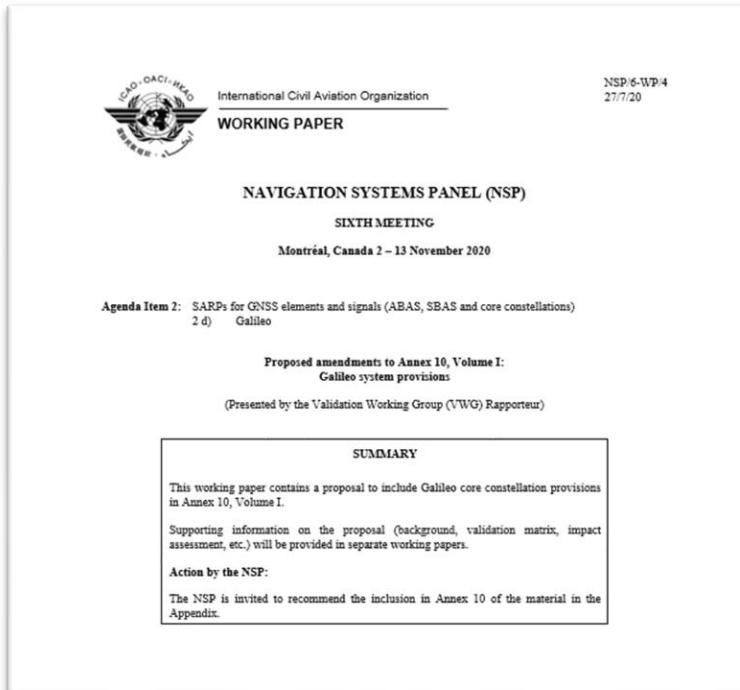
$P_{HMI}$  contribution of NOT-Monitored  
 $P_{THRES}=7e-8$





# ARTEX ACHIEVEMENTS AND OUTCOMES

# ACHIEVEMENT: ICAO GALILEO AND ARAIM SARPS



- ICAO **Galileo SARPS** was approved by ICAO in December 2020, based on validation material provided through GOSOL and ARTEX activities
- ICAO **ARAIM SARPS** approved November 2021
  - **Guidance Material** first draft (as attachment D, *green pages*) submitted to ICAO with large contribution from ARTEX ISMG ADD

# GALILEO FOR SOL USERS AND SUPPORT TO WGC



- A joint workplan with EC, ESA, EUSPA on Galileo supporting the development of Safety of Life applications was created and worked in the last years on the ARAIM definition
- Several activities were performed to support the ARAIM concept standardization at WGC, EUROCAE and RTCA level
  - Galileo Commitment definition
  - Integrity Support Message (ISM) definition
  - ISM Generator architecture and interface to Galileo Ground Monitoring
- Support to the drafting of the ARAIM CONOPS was performed and is on-going

# ISMG ALGORITHM DESCRIPTION DOCUMENT

- An **ISM Generation Algorithm Description Document** was shared with the Working Group C and provided input to the ISMG Guidance Material, which was included in the ICAO standard in November 2021 as part of the ARAIM SARPS.
- ISMG ADD will serve as input document for the development of the Operational Galileo ISMG
- Currently, the 3<sup>rd</sup> version of the document is under finalization.  
This version further addresses operational aspects of the Galileo ISMG

## Contributions to MOPS:

- *EUROCAE and RTCA joint working group has developed DFMC MOPS ED259a which includes ARAIM preliminary elements and is the basis for the future version (ED259b)*



# CONCLUSIONS

- The ARAIM concept is being implemented in Civil Aviation at International level. ICAO/RTCA/EUROCAE have included the main elements for its future deployment
- ARAIM is formally part of Galileo Mission in G2G. A dedicated WorkPlan was set up by the Programme and is conducting regular Reviews participated by EC/ESA/EUSPA and supported by Industry
- The ARTEX project has supported the development of the service within Galileo and in the International and standardization working groups
- Experimentation activities performed with the ARTEX demonstrator, including processing of Galileo real data since Initial Service Declaration
- Three important standards on ARAIM were recently approved by aviation fora: the Constellation Service Provider SARPS (including Galileo), the ARAIM SARPS and the DFMC MOPS