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Study of EGNOS V3 Maritime Safety Service Analysis

This presentation is based on SEASOLAS Project results.
SEASOLAS is a EC funded project

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CONTENTS

- Introduction
- SEASOLAS main results and challenges
  - Maritime Environment characterization
  - User Integrity Concept
  - Proposed EGNOS Maritime Safety Service Solution
- Conclusions

Introduction

INNOVATING SOLUTIONS

CONTEXT OF THE PROJECT AND GOALS

- SEASOLAS Project was funded by the European Commission (534/PP/GRO/RCH/16/9261)
- 18-month study: Jan 2017 – July 2018

- **Scope:** Define a Maritime Safety Service based on new receivers on-board vessels that uses EGNOS DFMC (EGNOS V3 will augment Galileo E1 and E5a and GPS L1 and L5 signals via geostationary satellites in L5) and based on a integrity concept at user level tailored for the maritime community

PRIME CONTRACTOR

ADVISORY BOARD

CONTEXT OF THE PROJECT AND GOALS

SBAS today: The SBAS ground infrastructure receives the GNSS signals, computes corrections and integrity information and broadcast them to SBAS-enabled receivers via GEO satellites.

- SBAS are implemented in different regions of the world and are interoperable: e.g. EGNOS in Europe, WAAS in northern America, GAGAN in India, MSAS in Japan, SDCM in Russia and SBAS Test Bed in Australia.
- Evolutions to Multi-frequency and Multi-constellation (DFMC)

Maritime context:

Maritime applications already use GNSS technology for navigation and positioning purposes. Two important IMO initiatives for SEASOLAS:

- **e-Navigation**: The shipping industry is moving towards an e-Navigation concept where a range of electronic and radio navigation technologies, including SBAS, will provide support for navigation in an harmonized, safe and secure way.

- **Multi-system Shipborne Receiver (MSR)**: The IMO Multi-system Shipborne Receiver (MSR) performance standards enable the full use of relevant data from current/future radio navigation system/services and other sensors. Therefore, it allows SBAS augmentation data processing.

SEASOLAS – EGNOS V3

EGNOS V3 maritime safety service will provide two main benefits for maritime users:

INTEGRITY AT USER LEVEL

User Integrity Concept

The **integrity** at user level is the **trust** that the user has in the position estimated by the receiver.

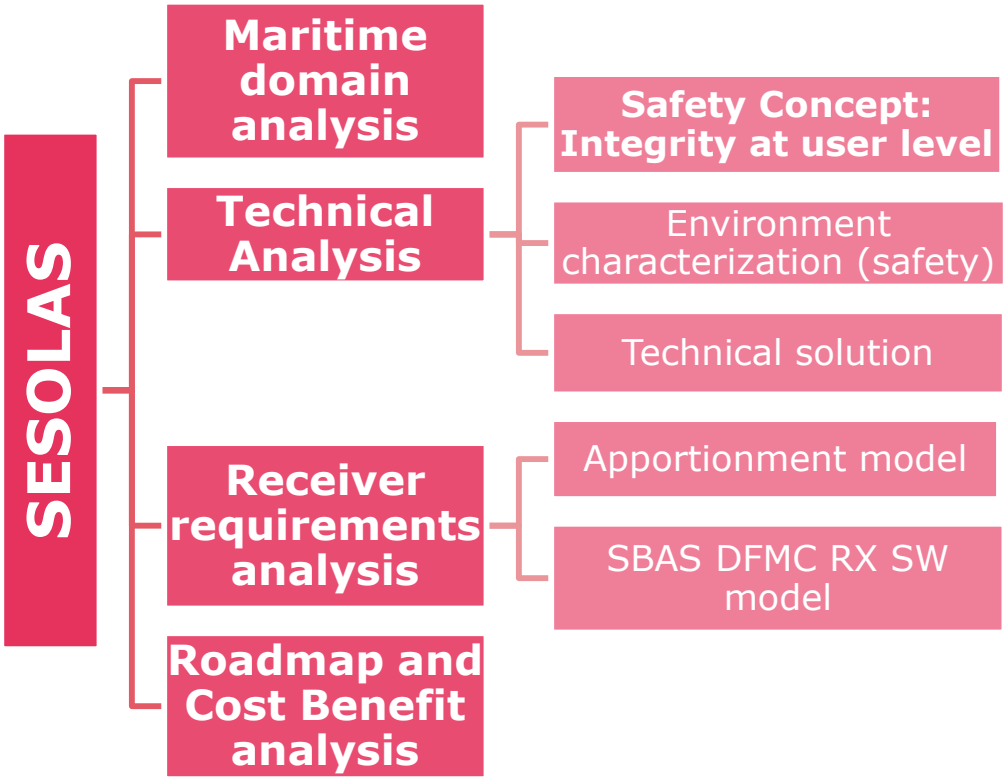
This **integrity** is the **enabler** to provide an **EGNOS maritime safety service**

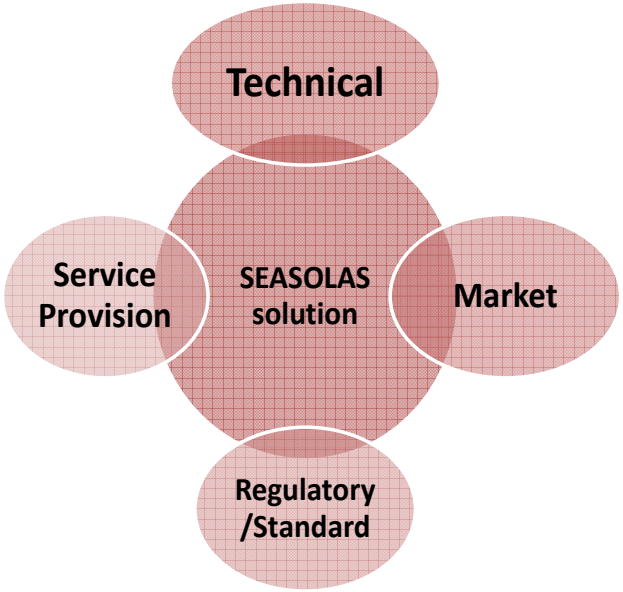
IMPROVED PERFORMANCES

Multi constellation, Multi-frequency Innovative approach

The **EGNOS V3** maritime safety service **improves performances and robustness** with respect to current technology thanks to the **multi-constellation** and **multi- frequency** capability.

TASKS ACCOMPLISHED BY THE PROJECT





- **GMV**: Project management, Leader of Technical Analyses (User Integrity, Technical solution, environmental characterization) and overall roadmap
- **ESSP**: Leader of Maritime Domain analyses and Service Provision aspects
- **Kongsberg (KSX)**: Leader of Receiver requirements analysis
- **GLA**: contribution to activities linked to operational needs, scenarios definition
- **VVA**: Responsible for CBA activities

Maritime environmental characterization

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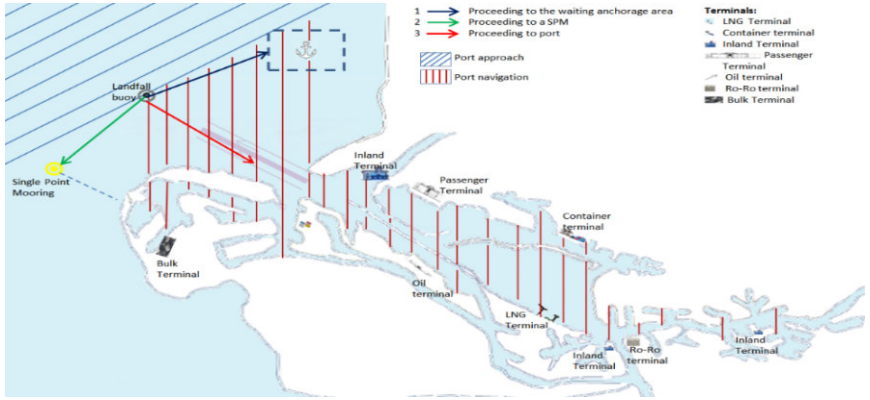
SEASOLAS WORST CASE SCENARIOS

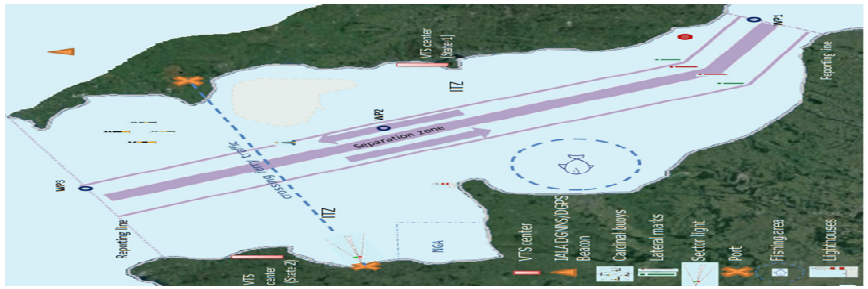


Port Navigation

- Demanding navigation phase in terms of performances from the user requirements perspective
- Complex scenario: Little space to manoeuvre, obstacles, Multipath,…
- High reliability, availability, integrity and continuity of the navigation solution (PNT)

Inland Waterways navigation (IWW)

- Narrow lanes, shared with many other vessels
- PNT reliability is a key element



Restricted waters. Traffic Separation Schemes (TSS).

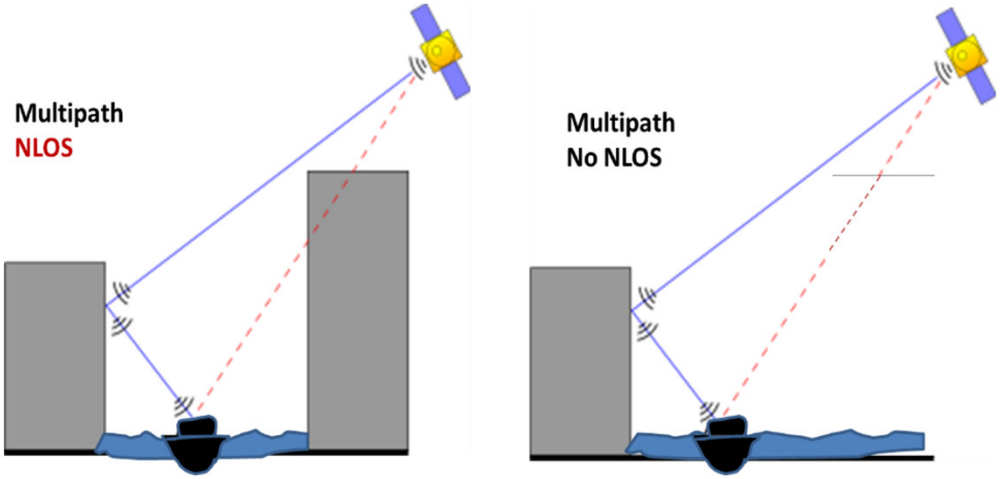
- High demand of safety service
- Defined lanes to be shared with other ships
- PNT reliability and continuity is a key element

MARITIME ENVIRONMENT

- Local effects in maritime domain can significantly degrade GNSS performances and which imply that the existing local error models may not be valid to safely represent these error contributions => require careful consideration and mitigation
- GNSS signals can be reflected or obscured by shore and port infrastructure, buildings and cargo stacks, vessel superstructures and sea surface

  – Multipath occurs when these reflected signals can interfere with signals directly received from the GNSS satellites

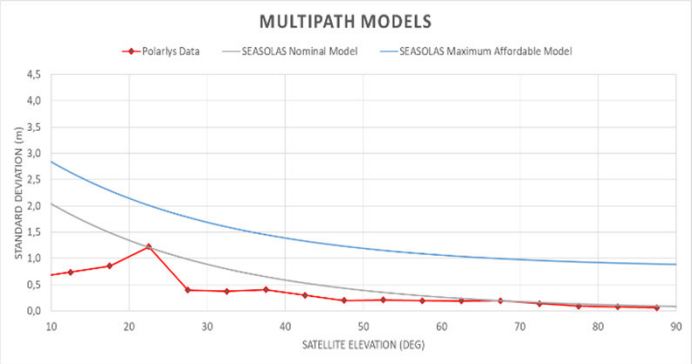
  – In the case of NLOS, the direct signal is blocked and only a reflected signal is received



SEASOLAS ENVIRONMENTAL CHARACTERISATION

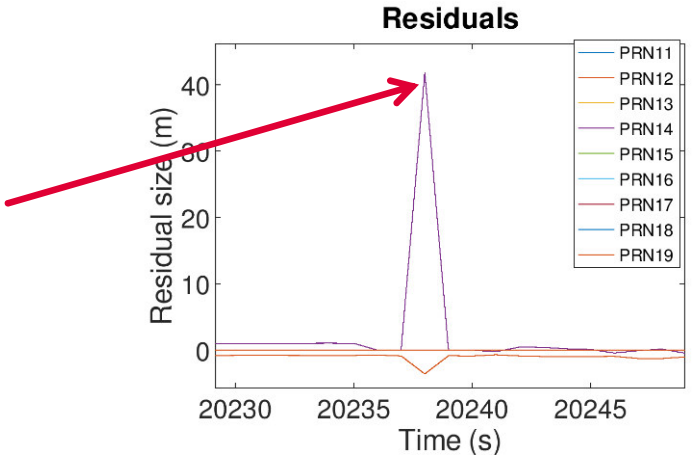
SEASOLAS analyzed whether the multipath error in the worst case scenarios can be safely represented by an overbounding mathematical model.

A **preliminary overbounding model** based on Jahn's formula was developed using real data: 3 months of data from a medium-sized cruise vessel navigating through Norwegian fiords.



Some extreme multipath events such as Non-Line of Sight (NLOS) were found in the same recorded data for the multipath model and from ad-hoc trials.

These NLOS events cause large measurement errors that no multipath error is able to overbound. Therefore, an additional technique is needed to deal these or other local events.



SEASOLAS ENVIRONMENTAL CHARACTERISATION– CONCLUSIONS AND RECOMMENDATIONS

- Need to **refine, validate and standardise the SEASOLAS multipath model**, performing a more extensive data collection and validation campaigns.
- Antenna installation highly affects the multipath error. It is strongly recommended to **standardise and monitor the installed receiver and the antenna location** within the vessel and the multipath test for a SoL navigation service.
- Due to the presence to NLOS or other local effects, other **methods in addition to the multipath model** are needed to ensure integrity at user level, dealing with these effects. Two different approaches are recommended:
  - Fault Detection (FD) and/or Fault Detection and Exclusion (FDE) techniques in order to ensure that only valid measurements are used.
  - To consider additional user integrity algorithms that are able to compute the navigation solution and protection levels taking into account or excluding these NLOS and other local events.

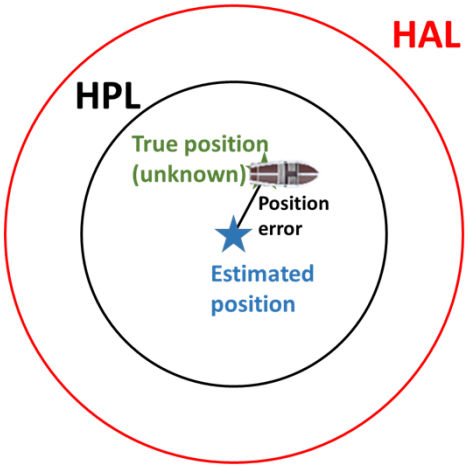
These points are addressed in the EGNOS Maritime Service implementation process managed by EUSPA

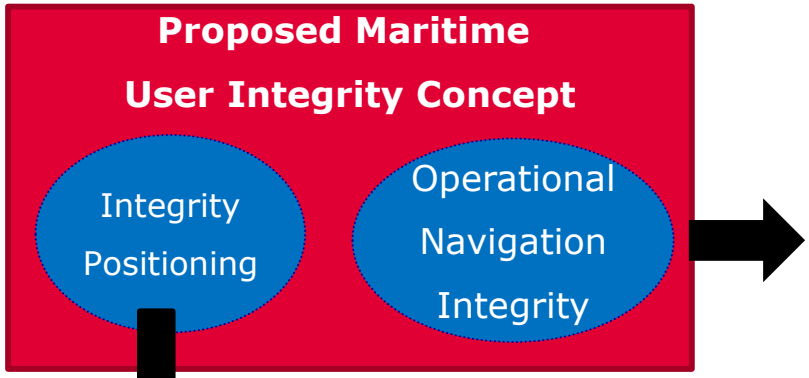
User Integrity Concept

SEASOLAS PROPOSED USER INTEGRITY CONCEPT(1/2)

Integrity positioning module:

Based on the computation of **H**orizontal **P**rotection **L**evels (HPL) adapted to maritime conditions





Operational navigation Integrity module:

- how this information (the protection levels) is used at shipborne level
- It includes two concepts:

ADAPTIVE SAFETY MARGIN + **ALERT CONCEPT**

Adaptive safety margins: the captain sees a region around its position, built from GNSS/SBAS solution (PLs), guaranteed at a certain level of probability, and allows him to make decisions.

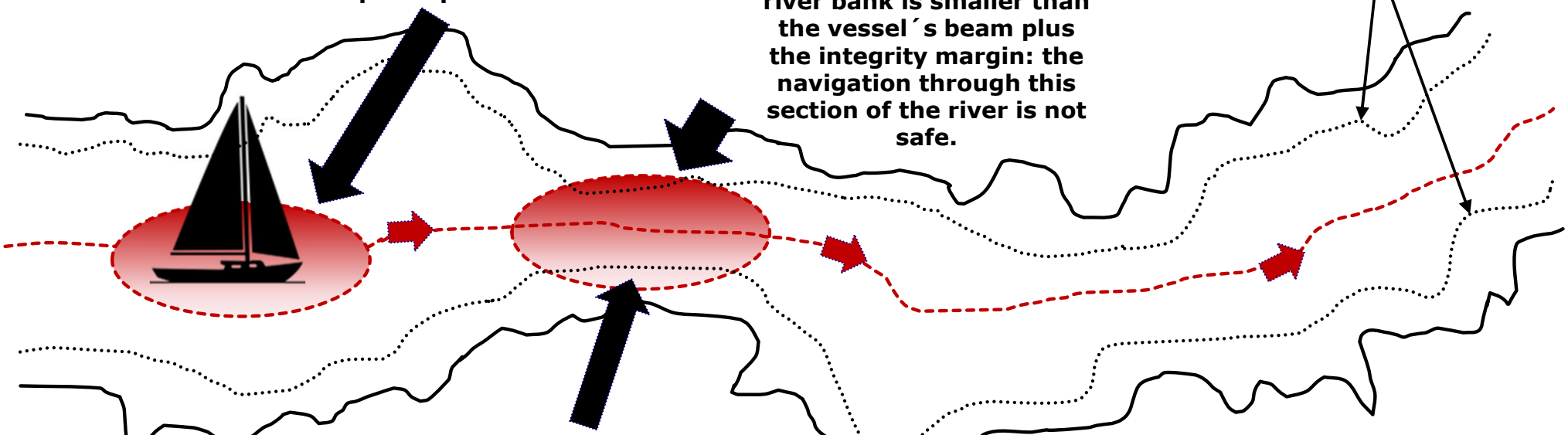
Navigation Traffic Lights concept: if a failure is detected, the user is promptly warned that the system shall not be used.

SEASOLAS PROPOSED USER INTEGRITY CONCEPT(2/2)

Proposed Integrity Concept for maritime: an integrity margin is estimated around the vessel´s structure to provide a measure on how reliable the vessel's position is. It provides confidence (with a certain probability) that the true position is within the bubble around the computed position.

Integrity Problem: The river bank is smaller than the vessel´s beam plus the integrity margin: the navigation through this section of the river is not safe.

Limits of the river´s section where vessels´ navigation is feasible (enough depth).



If vessel´s position is not accurately computed and its real position is approaching the river´s bank, then an accident could occur: the use of the integrity concept would avoid this issue.

An alarm will be raised in such case

Footnote to be added (thenounproject):

- Ship: Created by Jon Trillana from Noun Project

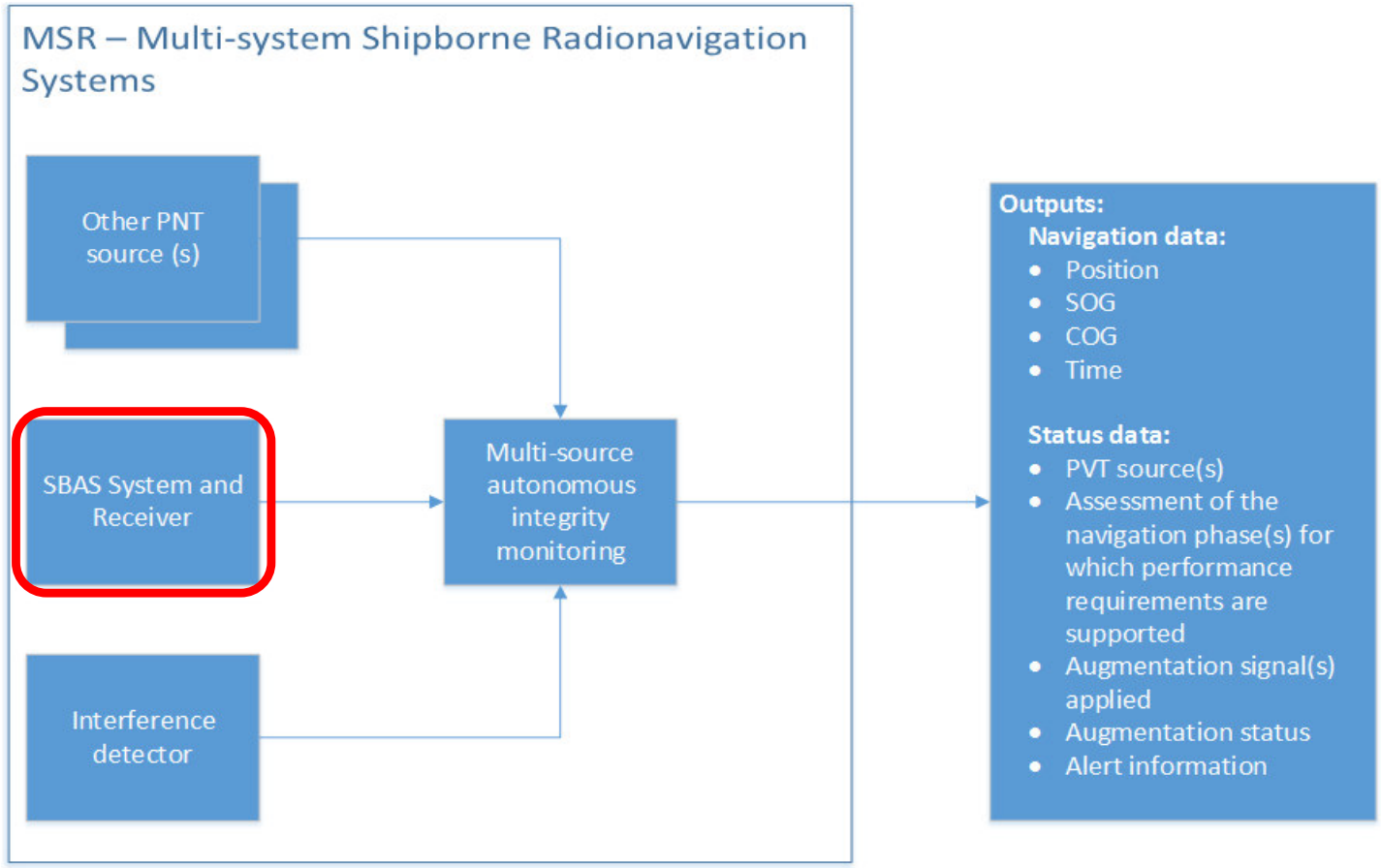
Proposed EGNOS Maritime Safety Service Solution

INNOVATING SOLUTIONS

SEASOLAS role of SBAS within MSR

SEASOLAS considers the existence of the following elements:

- An **SBAS DFMC receiver**
- An **interference detector**, which would prevent vulnerabilities against jamming, spoofing and other types of interference, regardless their origin.
- Other **PNT sources**, which will be used as a backup when the SBAS component is unavailable or presents discontinuity events.



SEASOLAS Technical Solution

Two main factors driving the solution: : maritime environment and stringent requirements

- **Option 1: SBAS enhanced with FD/FDE (SBAS+FD/FDE)**
  - SBAS DFMC solution enhanced with a Fault Detection/Fault Detection and Exclusion techniques at receiver level to detect and/or exclude hazardous local effects.
- **Option 2: SBAS enhanced with autonomous integrity algorithm (SBAS + Autonomous Integrity)**
  - SBAS DFMC solution including at receiver level (SBAS processing) and autonomous integrity algorithm to cope with local effects. In this case there is no need of having an overbounding multipath model associated to the integrity risk.
- **Option 3: SBAS enhanced with advanced PVT (PPP) and autonomous integrity(SBAS + PPP + Autonomous Integrity Algorithm)**
  - SBAS DFMC solution with PPP and integrity at user level. SBAS provides the PPP corrections (SBAS HA) and integrity is computed at user level.

The price of the first two solutions (including the antenna) is in line with the current market price. The third solution will be slightly more costly (due to PPP algorithm).

Non-recurring costs of the new receivers are also not significant (only SW update).

SEASOLAS Technical Solution

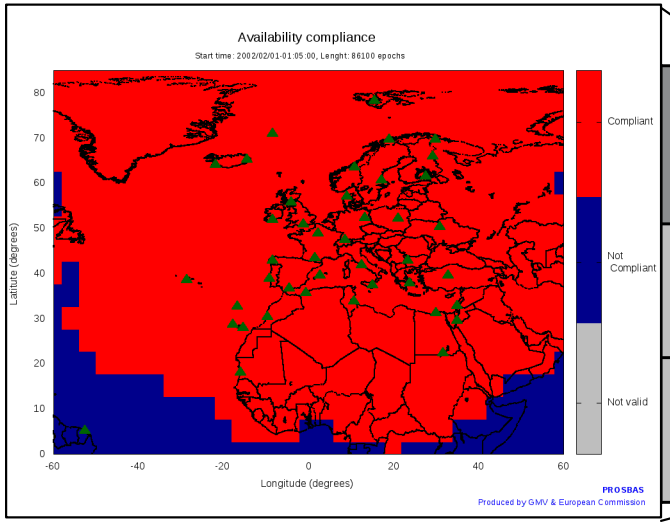
Summary of proposed SEASOLAS solutions per WCS

SEASOLAS WORST CASE SCENARIO	PROPOSED SOLUTION	
	IMO A.915(22) requirements	**Target Performance LEVELS**
WCS1: **Port navigation**	▪ SBAS DFMC Enhanced with advanced techniques (SBAS+PPP+Autonomous Integrity)	
WCS2: **Inland waterways**	▪ SBAS DFMC enhanced with FD/FDE. ▪ SBAS DFMC Enhanced with autonomous integrity	▪ SBAS DFMC Enhanced with autonomous integrity
WCS3: **Restricted waters: TSS navigation**	▪ SBAS DFMC enhanced with FD/FDE. ▪ SBAS DFMC Enhanced with autonomous integrity	▪ SBAS DFMC Enhanced with autonomous integrity ▪ *SBAS DFMC enhanced with FD/FDE.*

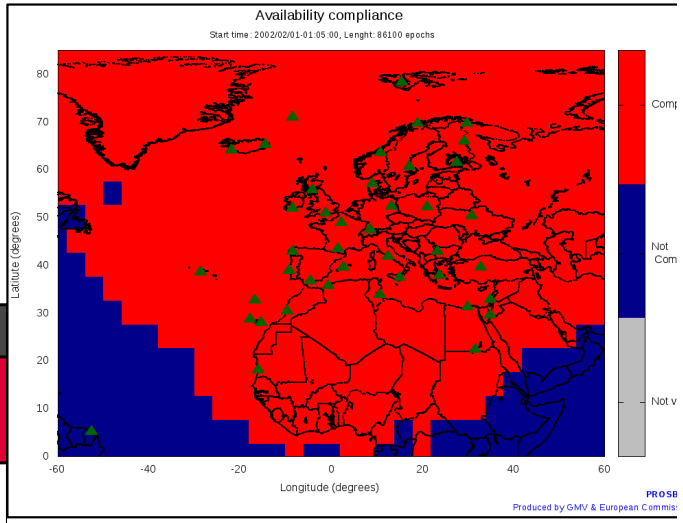
- **The SBAS DFMC enhanced with FD/FDE** solution is the proposed solution to fulfil the **IWW and TSS IMO requirements**. The SBAS DFMC Enhanced with autonomous integrity algorithm solution is also able to comply with these requirements.
- **The SBAS DFMC Enhanced with autonomous integrity** is the proposed solution able to comply the **IWW and TSS Target Performances Levels**, if precise OD&TS is considered.
- The **SBAS DFMC Enhanced with advanced techniques (SBAS+PPP+Autonomous Integrity Algorithm)** solution is the only feasible solution able to fulfil the **Port Navigation IMO requirements**.

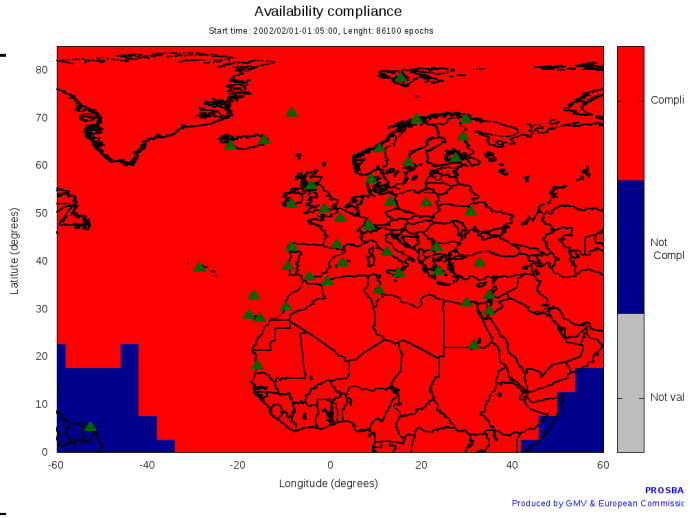
SEASOLAS Technical Solution

- **WCS2&3: Inland and Restricted Waters Navigation**



SEASOLAS WORST CASE SCENARIO	PROPOSED SOLUTION	
	IMO A.915(22) requirements	Target Performance LEVELS
WCS2: Inland waterways	HAL = 25m	HAL = 7,5m
WCS3: Restricted waters: TSS navigation		HAL = 12,5m



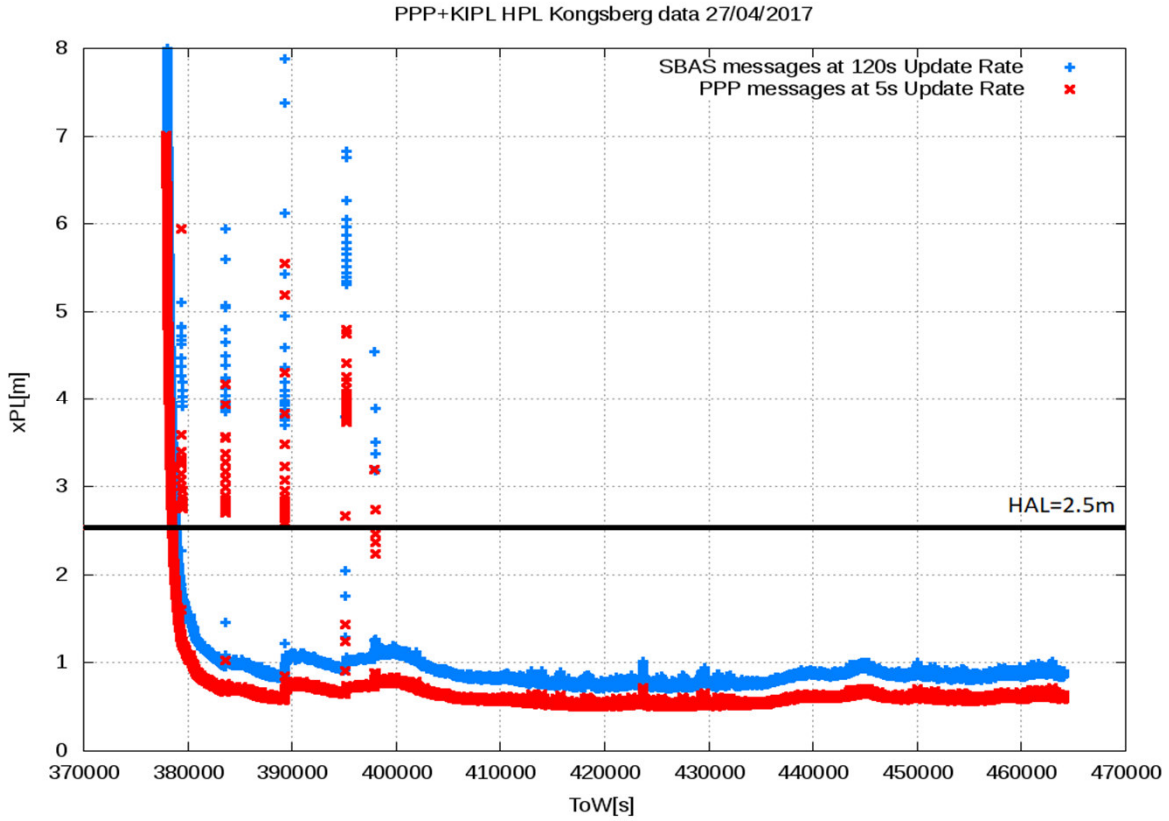


NOTE: Figures in this slide present availability performance. Continuity aspects need to be carefully assessed.

SEASOLAS Technical Solution

SEASOLAS WORST CASE SCENARIO	PROPOSED SOLUTION	
	IMO 915	Target Performance Levels
WCS1: Port	HAL = 2,5 m	

- **WCS1: Port Navigation**



HPL performance vs HAL=2.5 m
SBAS+PPP+Autonomous Integrity

- **Summary**
  - The **SBAS DFMC Enhanced with advanced techniques (SBAS+PPP+Autonomous Integrity Algorithm)** solution is the only feasible solution able to fulfil the **Port Navigation IMO requirements**.

SEASOLAS: Roadmap Critical activities

The following four main aspects are necessary to provide the EGNOS Maritime Safety Service:

- **Consolidation of the technical solution**: SEASOLAS has already identified many aspects which are required to be done in order to propose a technical solution for EGNOS V3. Special effort has to be done to work on these technical aspects as soon as possible in order to not delay the definition of the EGNOS V3 Maritime Safety Service and its corresponding adoption to the users.
- **IEC test specifications for the MSR**: having appropriate IEC test specifications for EGNOS V3 maritime safety service is a crucial aspect which may even delay the timely implementation of the Service.
- **Antenna installation:** the controlled antenna installation needs to be properly analysed to define the procedures the roles of the actors involved in this commissioning phase.
- **Maturity of user integrity concept based on human factors, including operational perspective:** this activity is needed to be able and to show the quantified benefits that the user integrity concept can bring to the maritime operations, e.g. sharing information between vessels in the same area.

It is also necessary to ensure **reciprocal education** between maritime users and the GNSS community.

These points are addressed in the EGNOS Maritime Service implementation process managed by EUSPA

Conclusions

INNOVATING SOLUTIONS

CONCLUSIONS

- Proposed new maritime SBAS receiver capable of providing user level integrity tailored for the maritime community
- This receiver was considered in line of newly developed MSR
- Stringent maritime conditions imply using additional elements within receiver to protect against multipath and NLOS
- Three technical solutions were proposed
  - SBAS DFMC enhanced with FD/FDE
  - SBAS DFMC enhanced with autonomous integrity algorithm
  - SBAS DFCM enhanced with advanced techniques
- Proposed user integrity concept which can be adapted to current maritime operations and equipment based on HPL concept

- An **EGNOS Maritime Safety Service** is **feasible** from a technical point of view.
- More work is needed on the development of the different algorithms at receiver level (continuity performance, assumptions, etc.)
- New "approved" maritime receiver/antenna installation approach is also needed.

These points are addressed in the EGNOS Maritime Service implementation process managed by EUSPA

Thank you for your attention !!

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GNSS PERFORMANCES: GENERAL VIEW

- GNSS SIS performance requirements are expressed in terms of:
  - **Accuracy**: difference between the real position and the one provided by the navigation system
  - **Integrity**: measures the confidence in the correctness of the information supplied by the system
  - **Continuity:** probability that the specified system performance will not be interrupted for the duration of a phase of operation, assuming that the system was available at the beginning of that phase of operation
  - **Availability:** ability of the system to provide the required function and performance at the initiation of the intended operation

In the three SEASOLAS scenarios, not only enough accuracy performance is required but also high integrity and continuity of positioning. The user requirements of these scenarios are based on the current international standards (IMO A.915(22)).

SEASOLAS USER REQUIREMENTS – IMO REQUIREMENTS

In the three SEASOLAS scenarios, not only enough accuracy performance is required but also high integrity and continuity of positioning. The user requirements of these scenarios are based on the current international standards (IMO A.915(22)).

	System Level Parameters					Service Level Parameters			
	Accuracy		Integrity			Availability % per 30 days	Continuity % over 15 minutes	Coverage	Fix interval seconds
	Horiz. (m)	Vert. (m)	Horiz.Alert limit (m)	Time to alarm (s)	Integrity risk per 3 hours				
General Navigation									
Port navigation	1	N/A	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	N/A	25	10	10^{-5}	99.8	99.97	Regional	1
Restricted waters: TSS navigation	10	N/A	25	10	10^{-5}	99.8	99.97	Regional	1

SEASOLAS USER REQUIREMENTS – TARGET PERFORMANCE LEVELS

Worst-case scenario	IMO A.915(22) requirements		Target Performance	
	HPE 95% (m)	HAL_{REG} (m)	HPE 95% (m)	HAL_{TEC} (m)
Port navigation	1	2.5	1	2.5
Inland waterways	10	25	3	7.5
Restricted waters: TSS navigation	10	25	5	12.5

IMO

Requirements from regulation already accepted by the maritime community

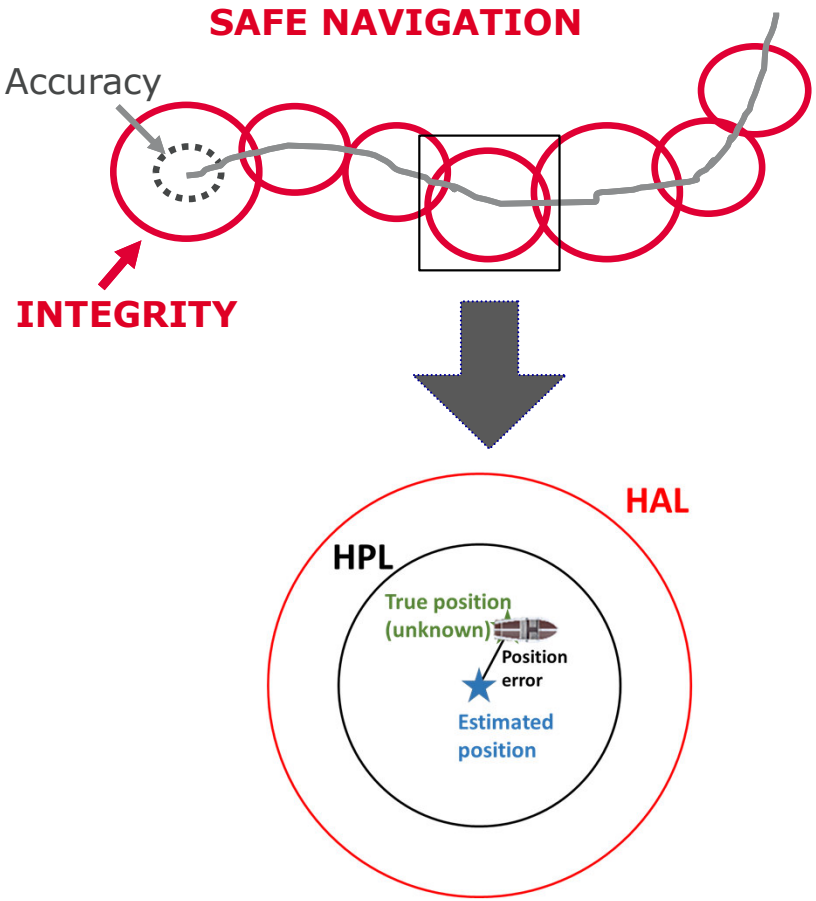
These values aim to explore if the technology allows fulfilling more stringent requirements that the regulated ones

Horizontal Position Error (HPE): typical accuracy value of the position error expressed in statistical terms (e.g. percentile 95)

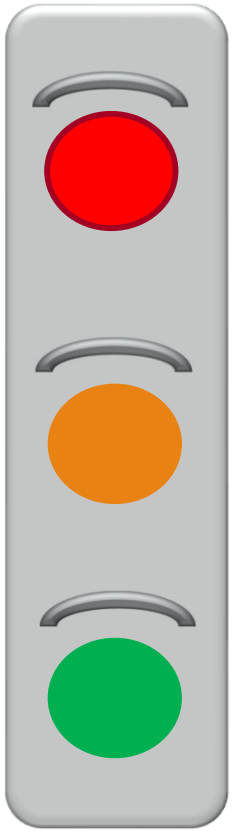
Horizontal Alarm Limit (HAL): error tolerance not be exceeded without issuing an alert

SEASOLAS PROPOSED USER INTEGRITY CONCEPT

ADAPTIVE SAFETY MARGIN



ALERT CONCEPT



IF HPL>HAL_{REG}

An alarm is raised!!

Operation not permitted

IF HAL_{REG}>HPL>HAL_{TEC}

A warning is raised

HAL_{TEC}

IF HPL<HAL_{TEC}<HAL_{REG}

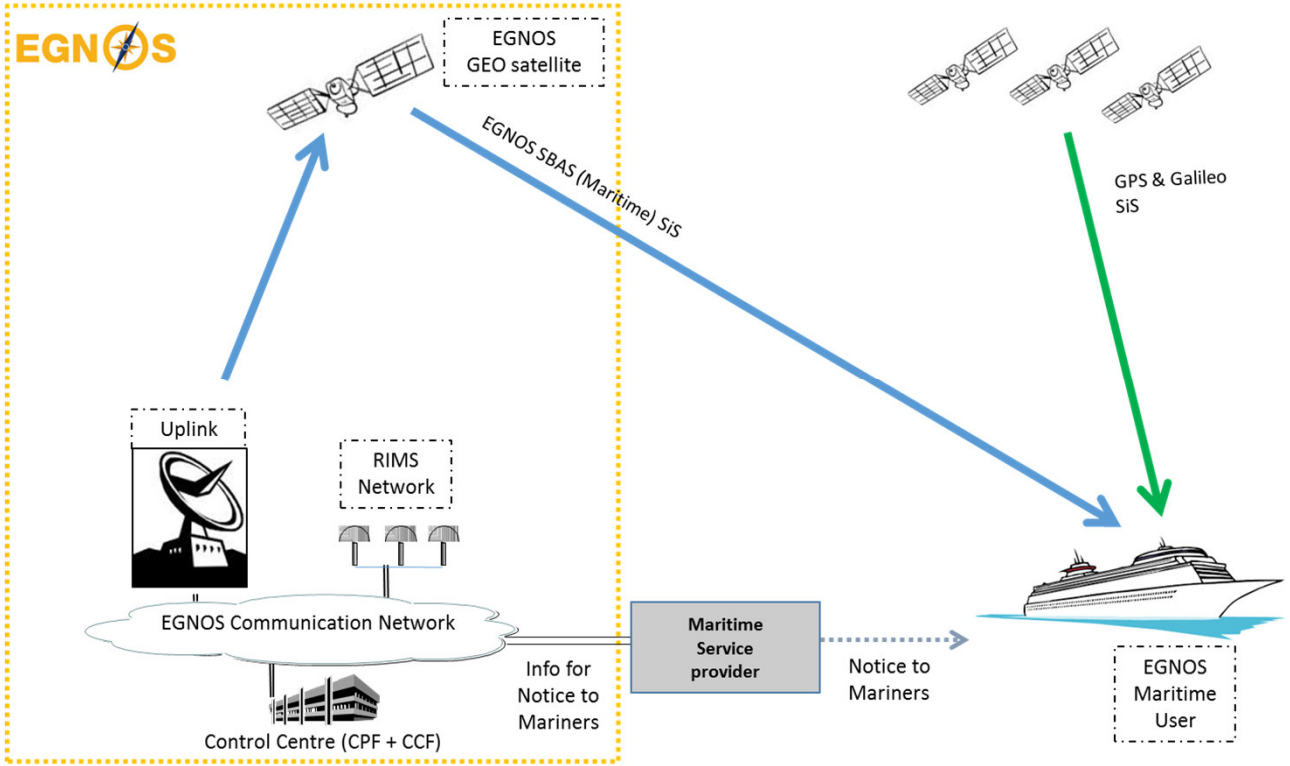
SAFE OPERATION!!

HAL_{REG}: HAL linked to regulations (IMO 915)

HAL_{TEC}: Technical HAL, linked to the Target Performance Levels. In line with Multi-system Shipborne Radionavigation (MSR) approach from IMO Circ. 1575

SEASOLAS EGNOS V3 System Architecture

A preliminary High-level view of the Service is detailed in the figure:



Three main segments

- **Space segment:** consisting on GNSS transponders installed in GEO satellites.
- **Ground segment:** including reference stations (RIMS), mission control centres (MCC), uplink stations (NLES) and communication network (EWAN).
  - Includes the support segment, with components to analyse performance and carry out maintenance and engineering activities.
- **User segment,** composed of the user receivers able to get GPS and Galileo raw measurements and EGNOS messages.

MARITIME ENVIRONMENTAL CHARACTERISATION

(*) This is standardised for the EGNOS SoL but up to the receiver manufacturer for EGNOS OS.

Additional corrections **depend on a user location+environment** and are calculated on the user side:

- Multipath
- Receiver thermal/tracking noise
- Shadowing
- Local interference

and used on top of the corrections received from the EGNOS signal

=> Bound of the residual error that users can expect (i.e. user-level integrity)

These corrections will be different from aviation for a maritime user; models used are **fixed during receiver design** (*)