GNSS Integrity

Lantmäteriet, SWEPOS
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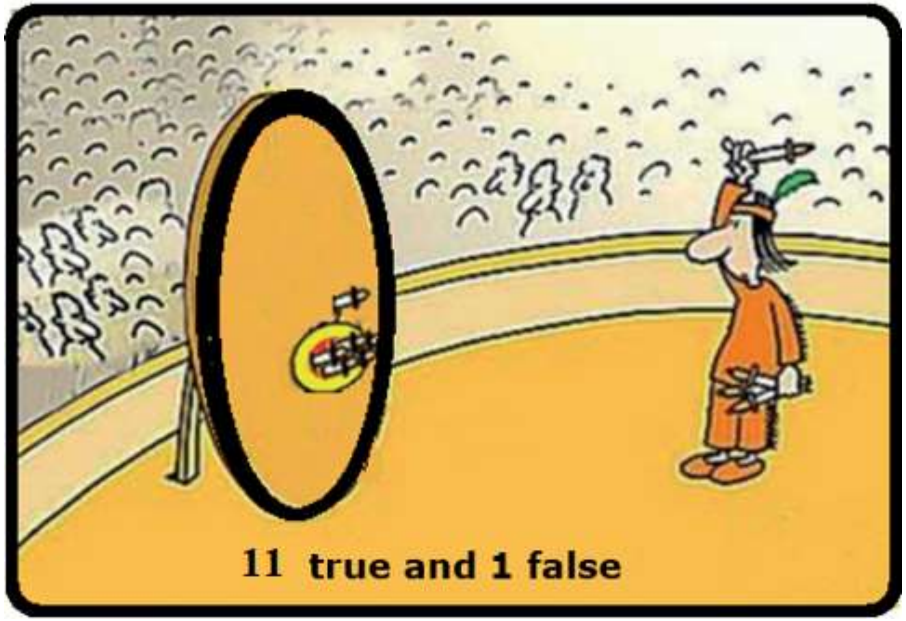
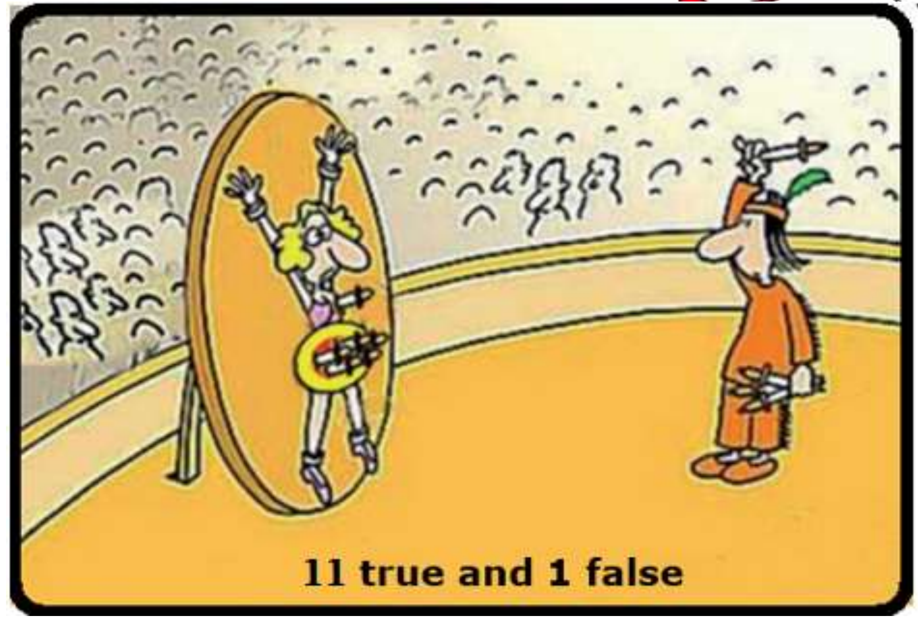
Outlines

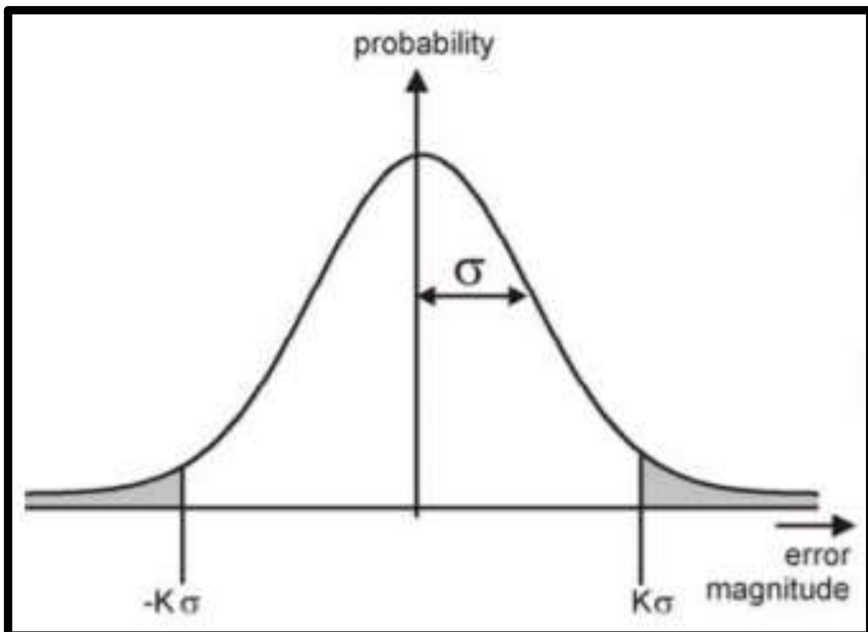
- What is the integrity?
- Integrity Parameters.
- Integrity requirements.
- Integrity Algorithms/applications.

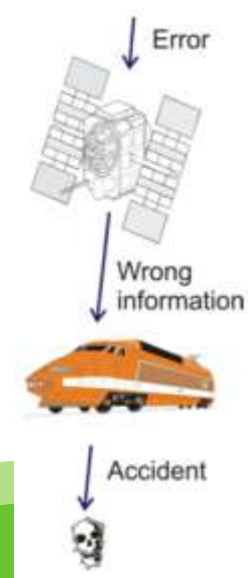
What is the GNSS integrity?

What do you think about the knife thrower?



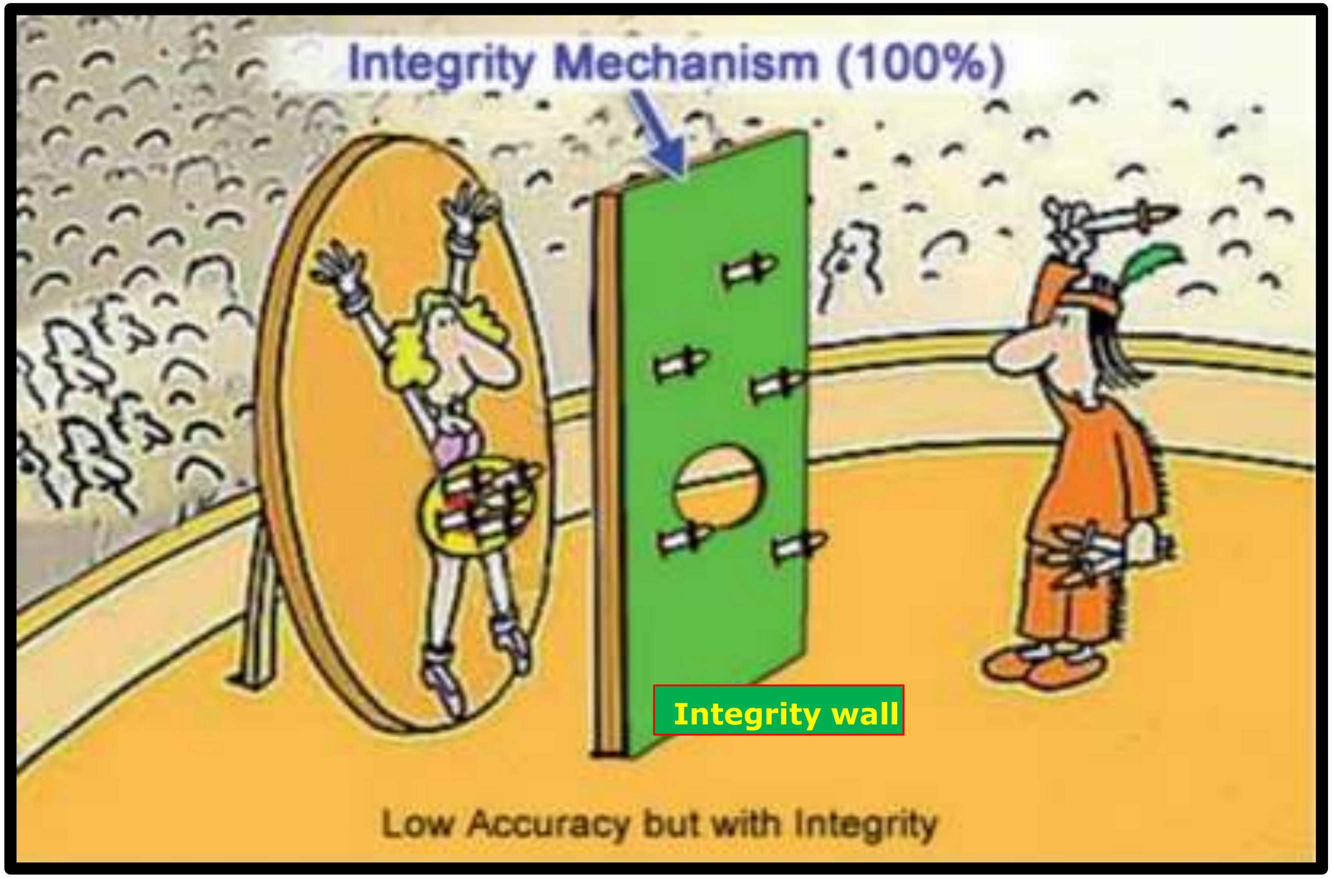






Safety-of-Life (SoL) applications.

What is the GNSS integrity?



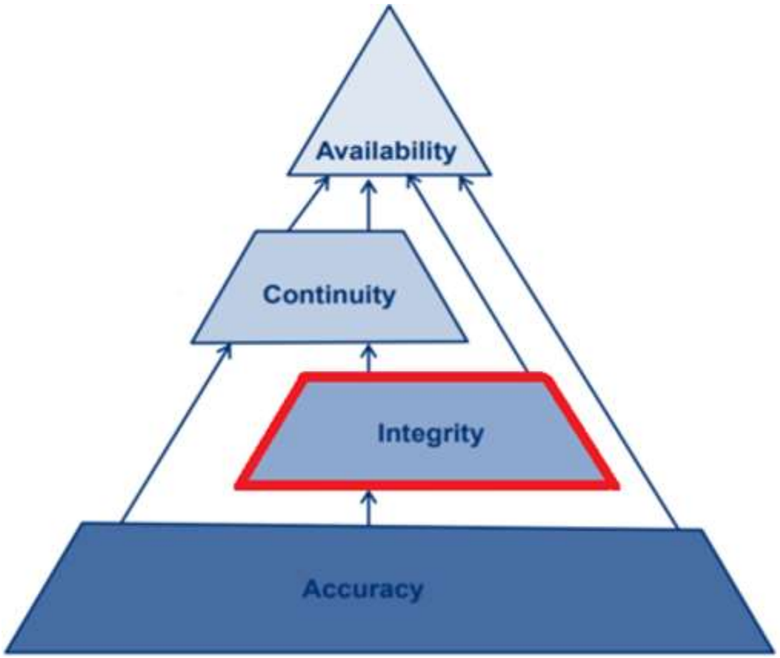
How to build the trust 'Integrity wall' while using GNSS ???

What is the GNSS integrity?

- "*Integrity: the ability of a navigation system to provide timely warnings to users when the system should not be used*". Source-Federal Radionavigation Plan

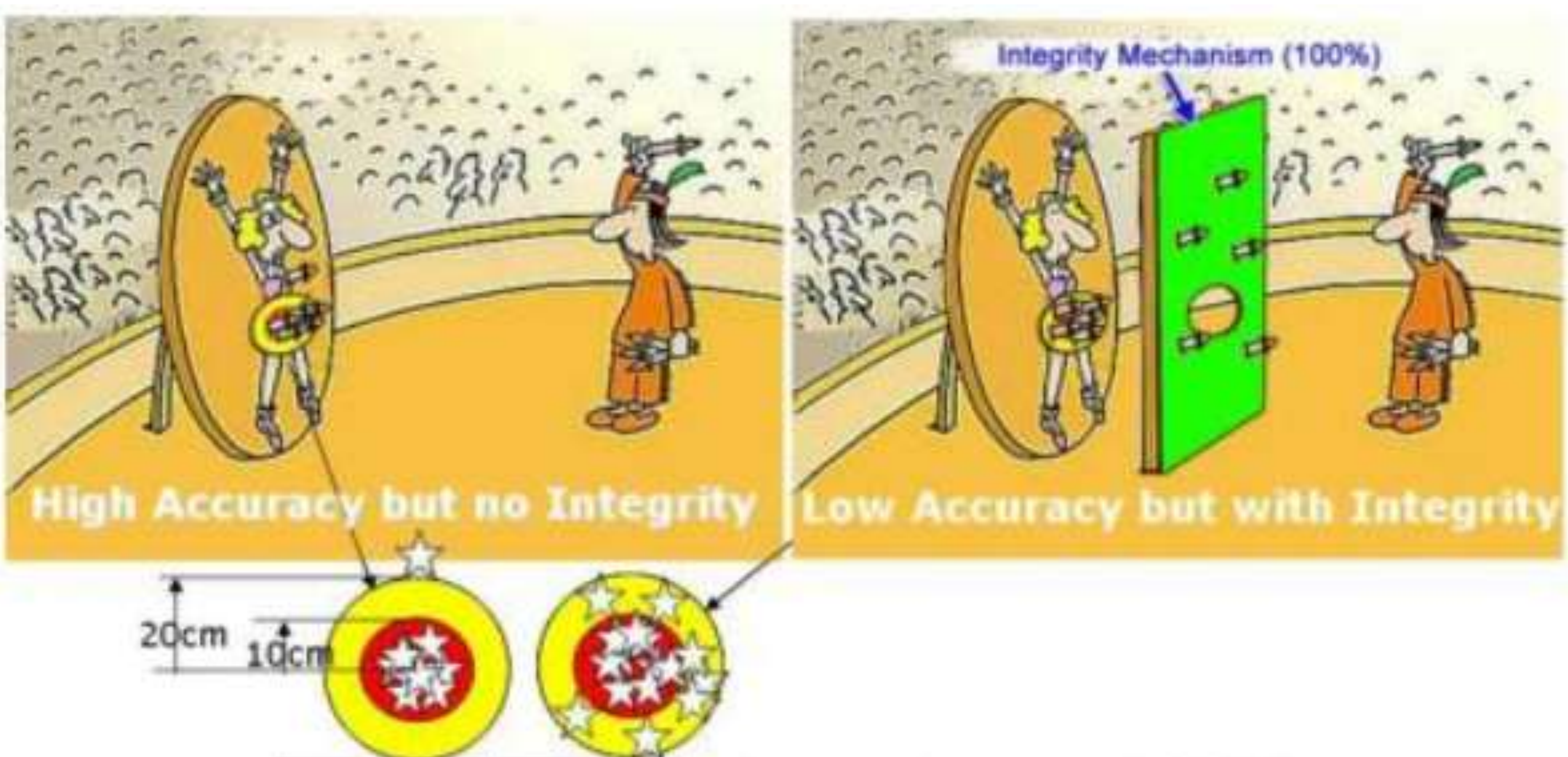
- **GNSS performance** means mainly the four GNSS quality attributes:

  Accuracy, Integrity, Continuity and Availability



(GNSS Navigation Performance Pyramid)

Integrity vs. Accuracy

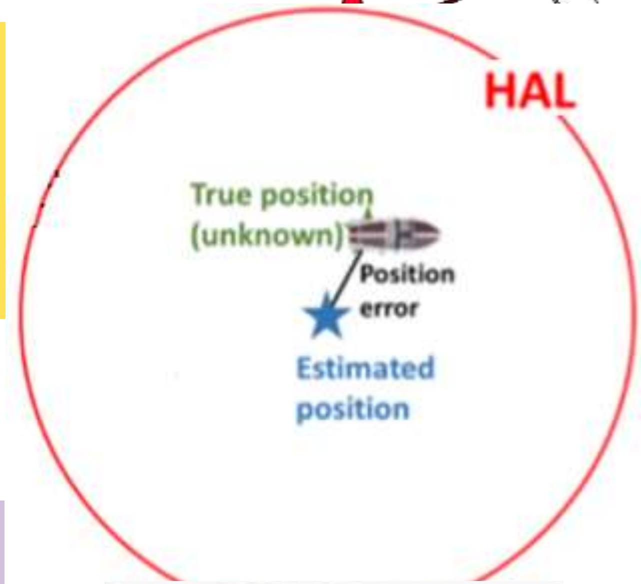


8 cm	18 cm	Accuracy (e.g. error at 95%)
99%	100%	Integrity (percentage inside the yellow circle)

GNSS Integrity parameters

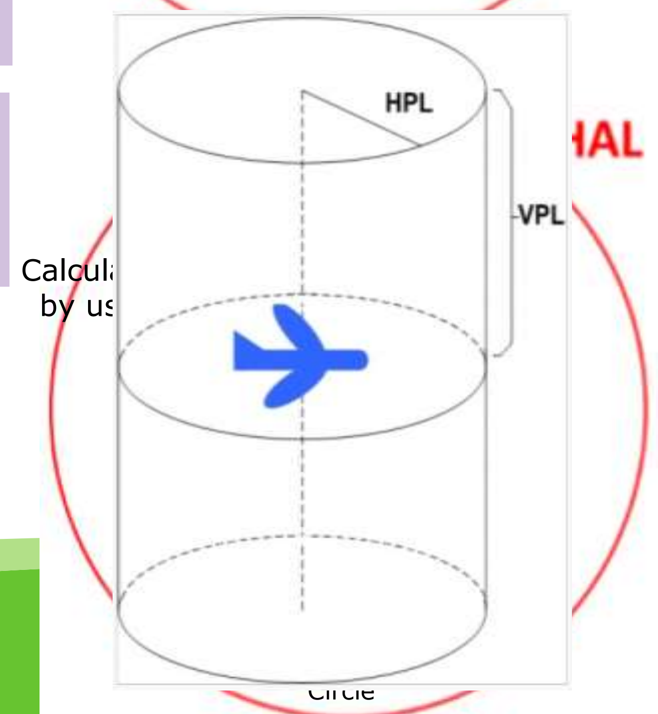
- **Alert Limit (AL):** The largest position error allowable for safe operation. (It is the radius of a circle which describes the region that is required to contain the indicated position with the required probability for a particular navigation mode).

- **Time to Alert (TTA)**



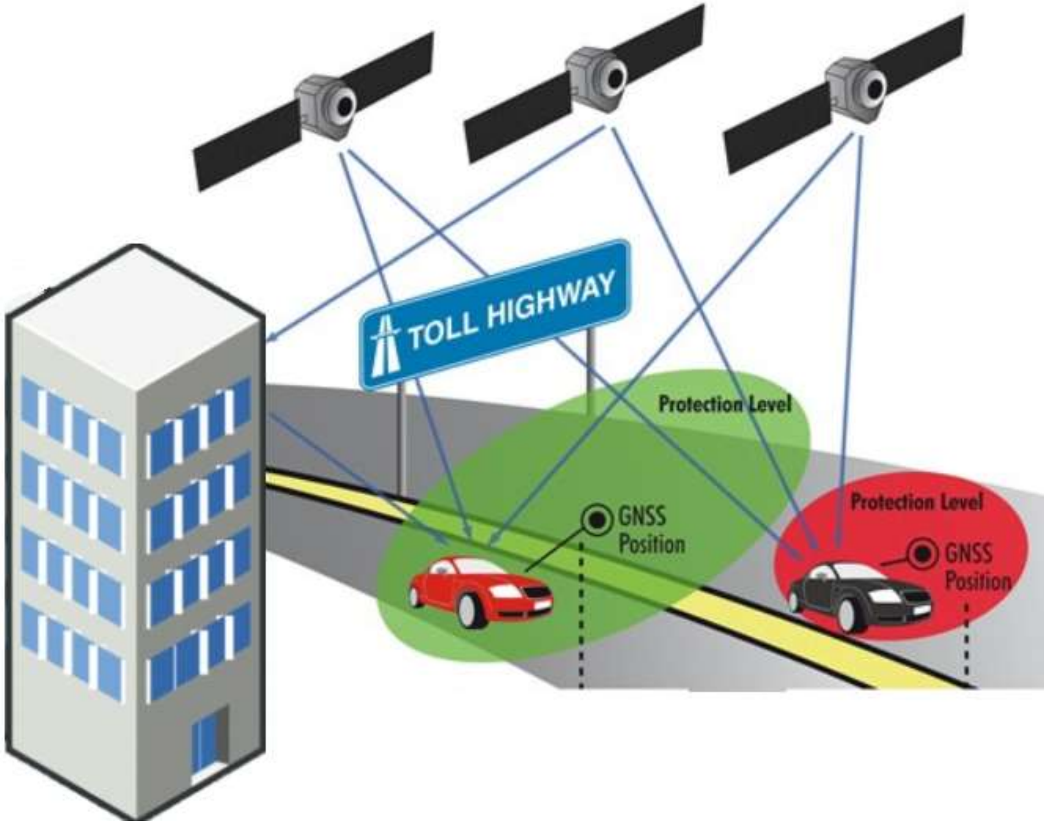
- **Protection Level (PL)**: It is the key to the integrity concept. ??

- PL concept was devised to inform users of the degree of residual risk of large position errors after *integrity monitoring* is completed.



  - If PL > AL, the alert triggers;
  - If PL < AL, the alert does not trigger

Protection Level Concept



-User compute the Protection Level.

-The PL may vary between epochs according to the <u>type</u>, <u>quality</u>, <u>geometry</u> and <u>number</u> of **observations**, as well as the functional model used.

-To accept the solution at a certain epoch, the computed values of PLs should not exceed a threshold alert limit.

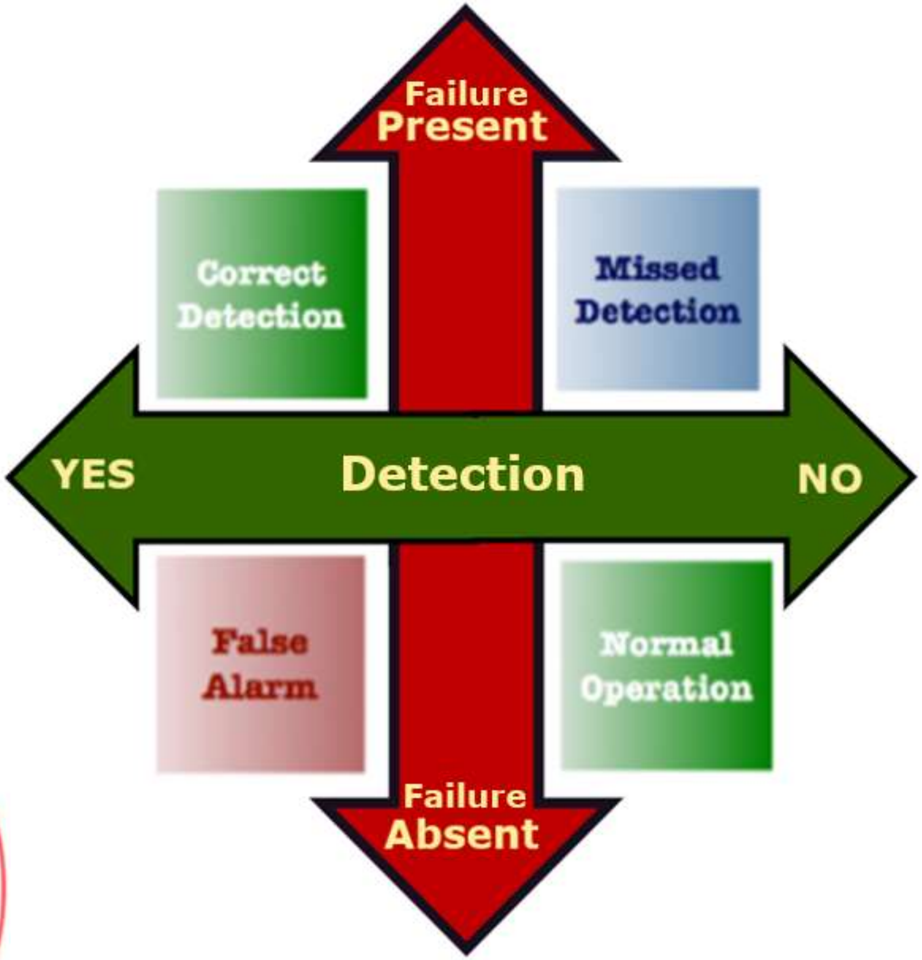
$$PL = k \cdot \sigma_{UERE,eff} \sqrt{trace\left[\left(\mathbf{H}^{T}\mathbf{H}\right)^{-1}\right]}$$

Multiplicative factor related to the **integrity risk requirements**

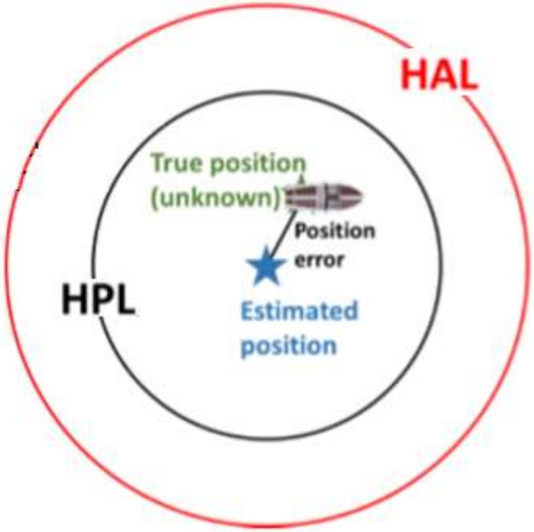
<u>**New error model**</u>, taking into account **local GNSS signal degradations**

Factor related to the **satellite geometry** (Dilution of Precision)

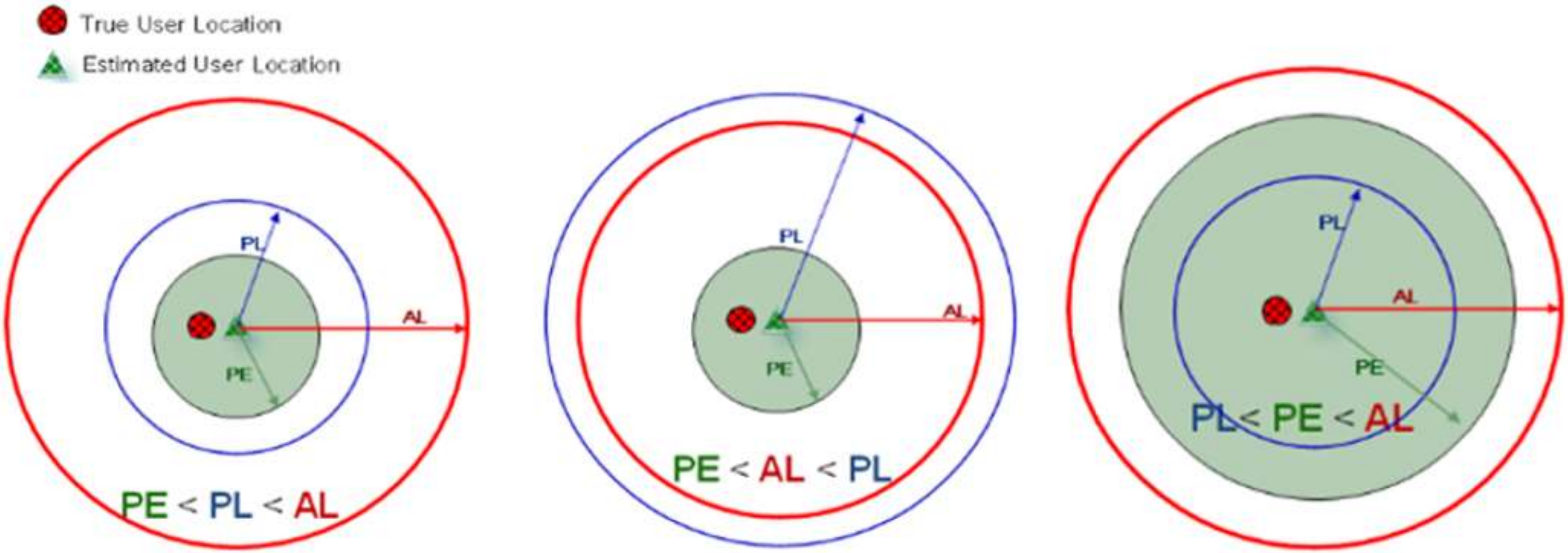
Integrity Statistical Decision Outcomes



GNSS Case?



Integrity Operational Modes



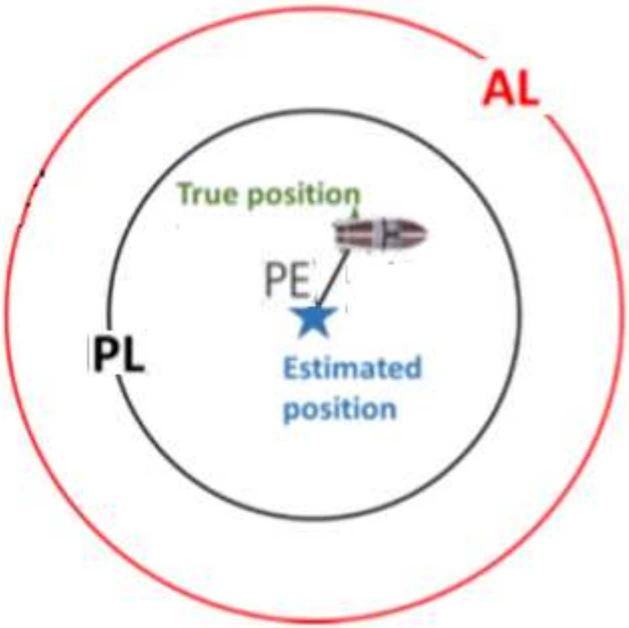
Nominal Operations

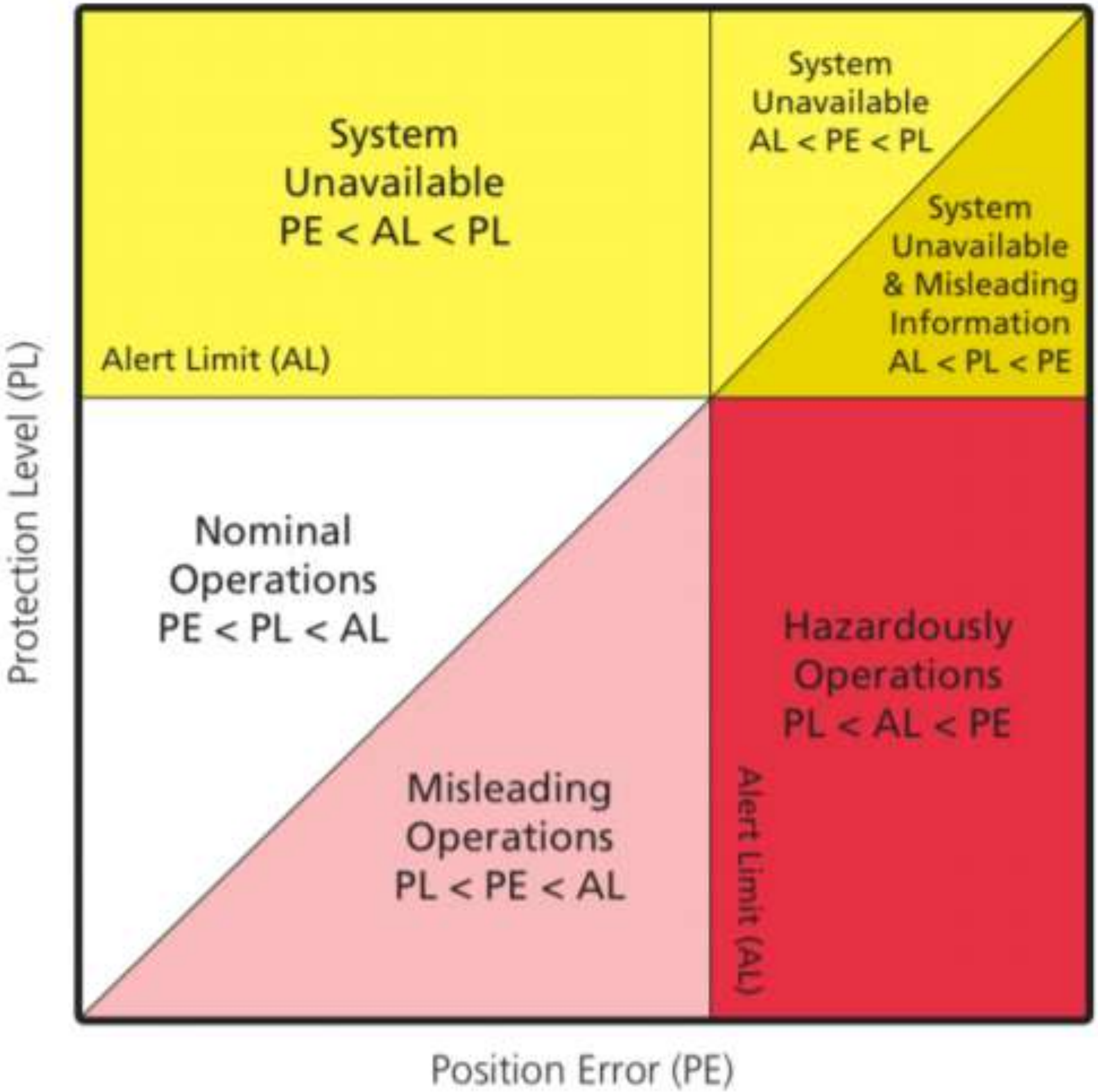
System Unavailable

Misleading Operations

Stanford Integrity Diagram

It uses now for SBAS



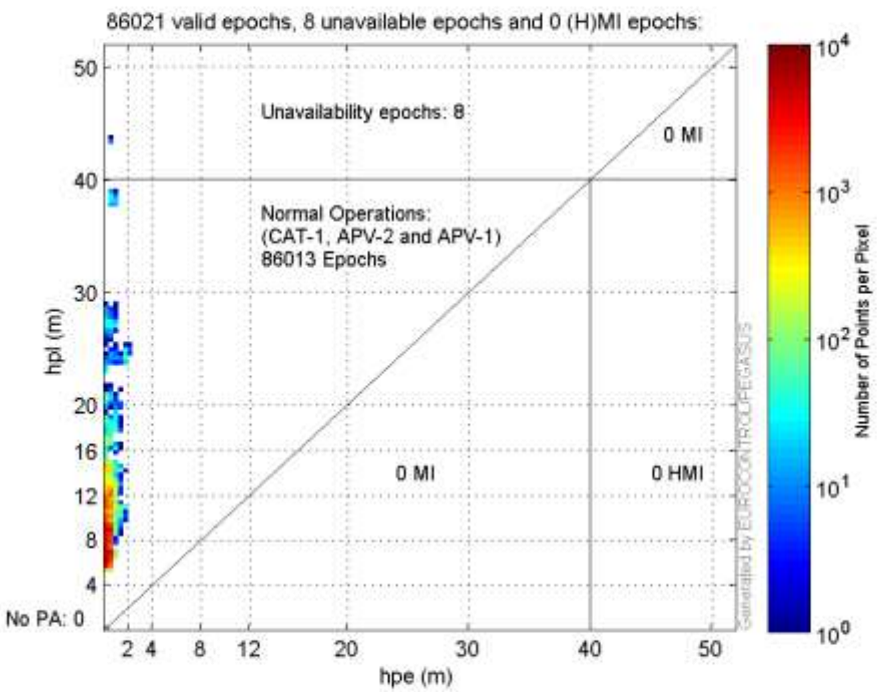


Practical example of using the Stanford Integrity Diagram

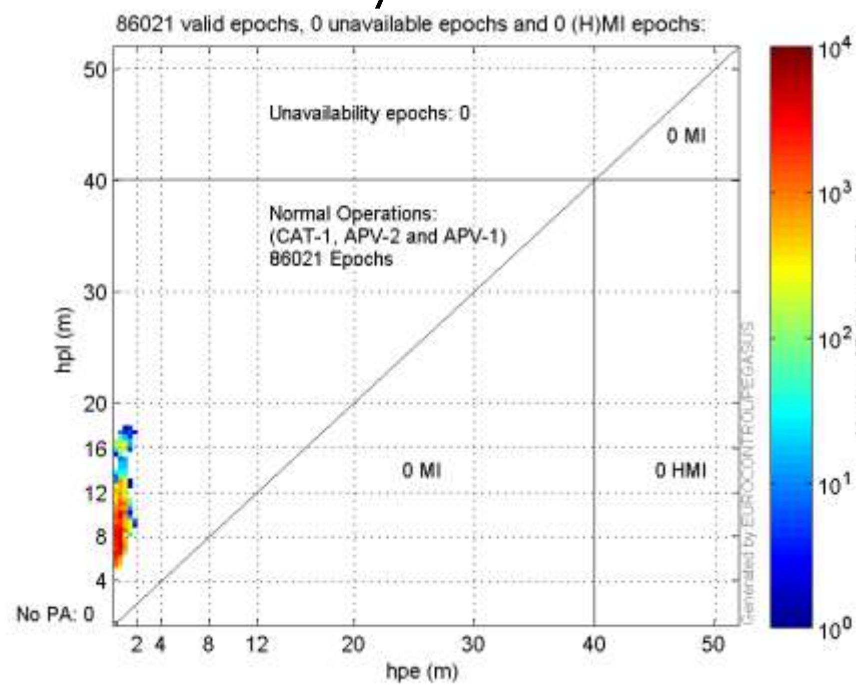
EGNOS Service Performance Monitoring Support (SPMS) project

DOY 280 (2018-09-07), PRN 136

Överkalix station



Visby station

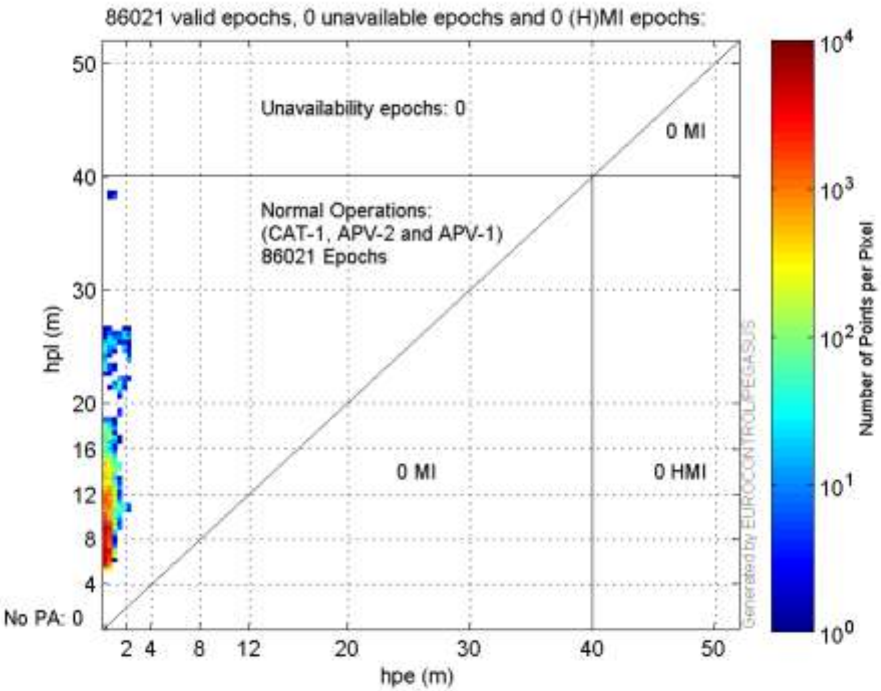


Practical example of using the Stanford Integrity Diagram

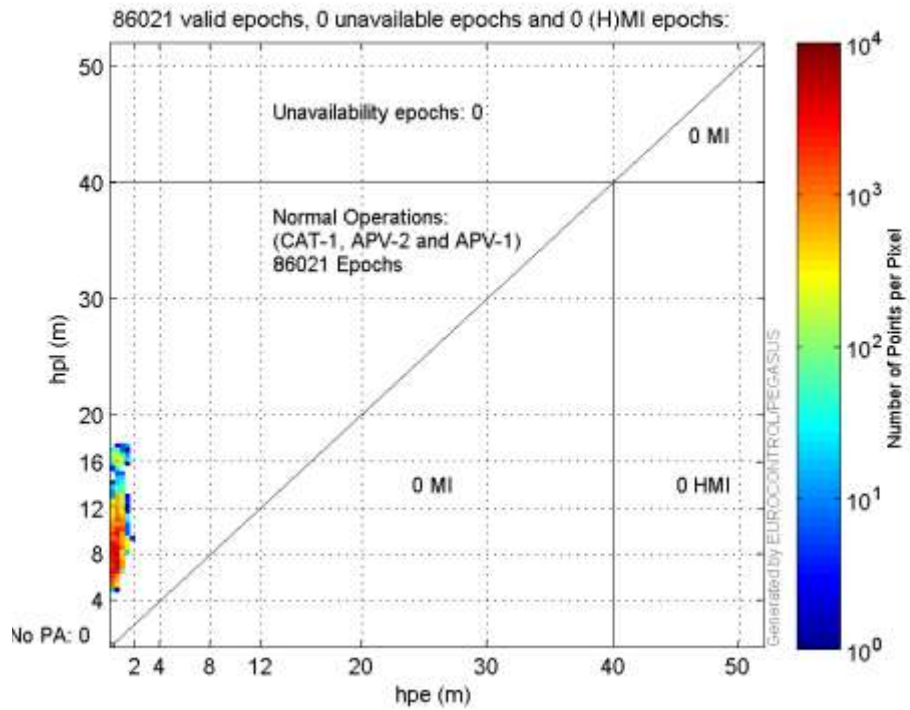
EGNOS Service Performance Monitoring Support (SPMS) project

DOY 280 (2018-09-07), PRN 123

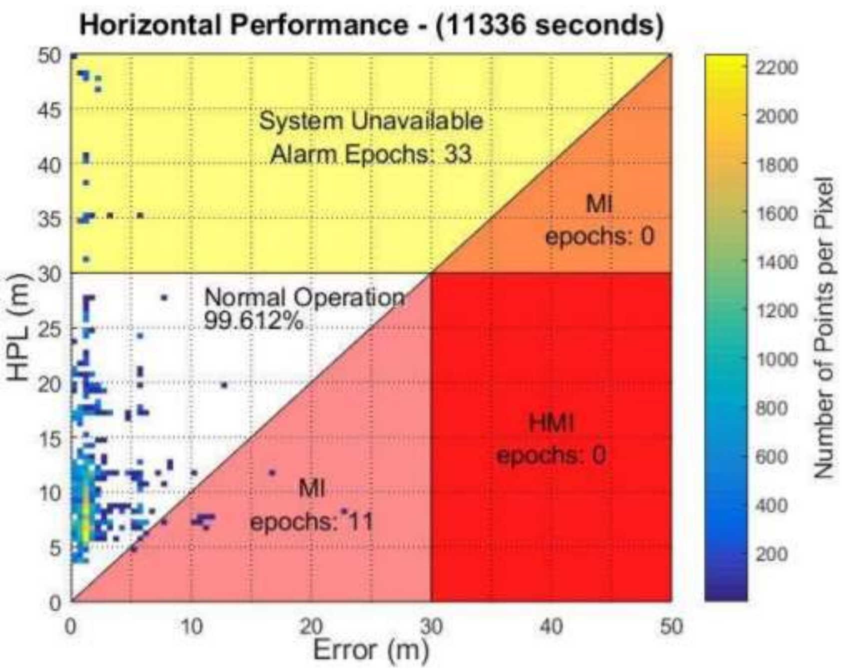
Överkalix station

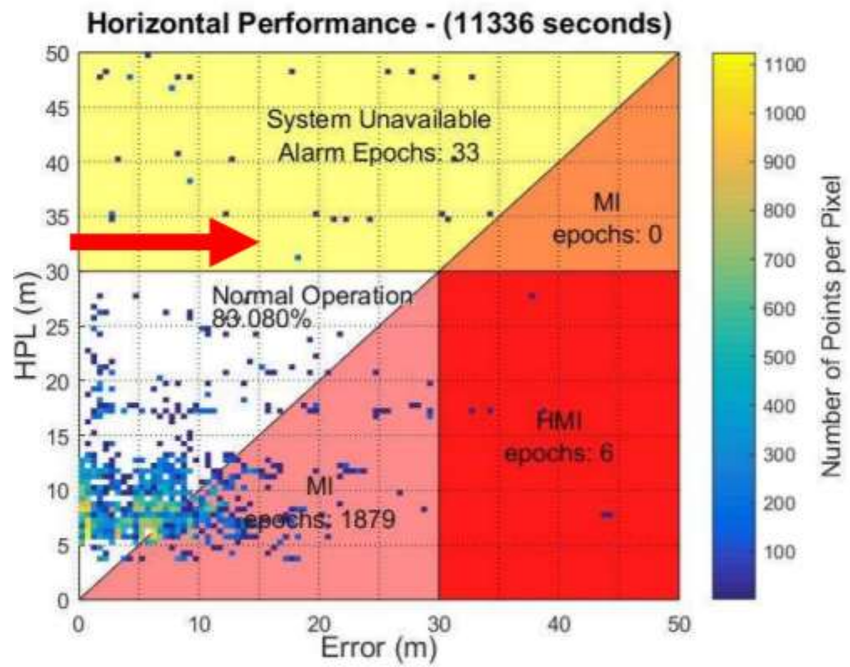


Visby station



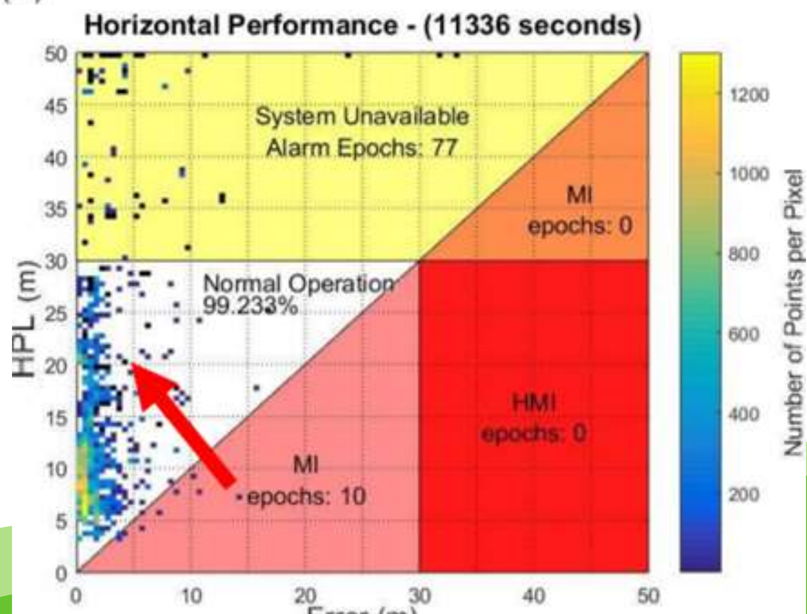
Example: Multipath error.





Adding manually pseudorange error 20 m (Multipath) added to 1 random satellite 50% of the time

Integrity algorithm carried out on data with manually added pseudorange error



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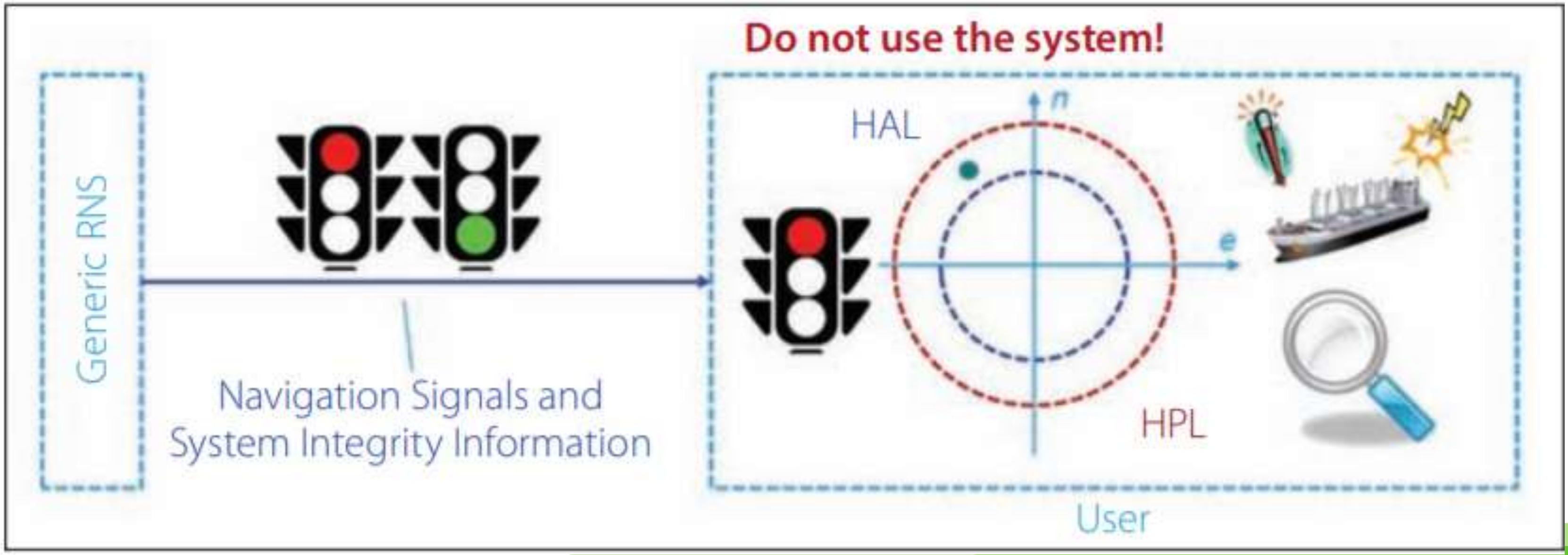
Integrity monitoring layers

The primary defense against the faulty signals (Filtering)

(exclude them from use and work with the remaining healthy signals).

Protection Level Calculations

(signals that pass all monitors still contain some risk of producing large errors)



Examples for Integrity requirements

International Civil Aviation Organization (ICAO)

Typical operation	Horizontal alert limit	Vertical alert limit	Integrity risk	Time-to-alert
NPA	556 m	N/A	$1-1\times10^{-7}$/h	10 s
APV-I	40 m	50 m	$1-2\times10^{-7}$ in any approach	10 s
APV- II	40.0 m	20.0 m	$1-2\times10^{-7}$ in any approach	6 s
Category I	40.0 m	35.0 m to 10.0 m	$1-2\times10^{-7}$	6 s

The International Maritime Organization (IMO)

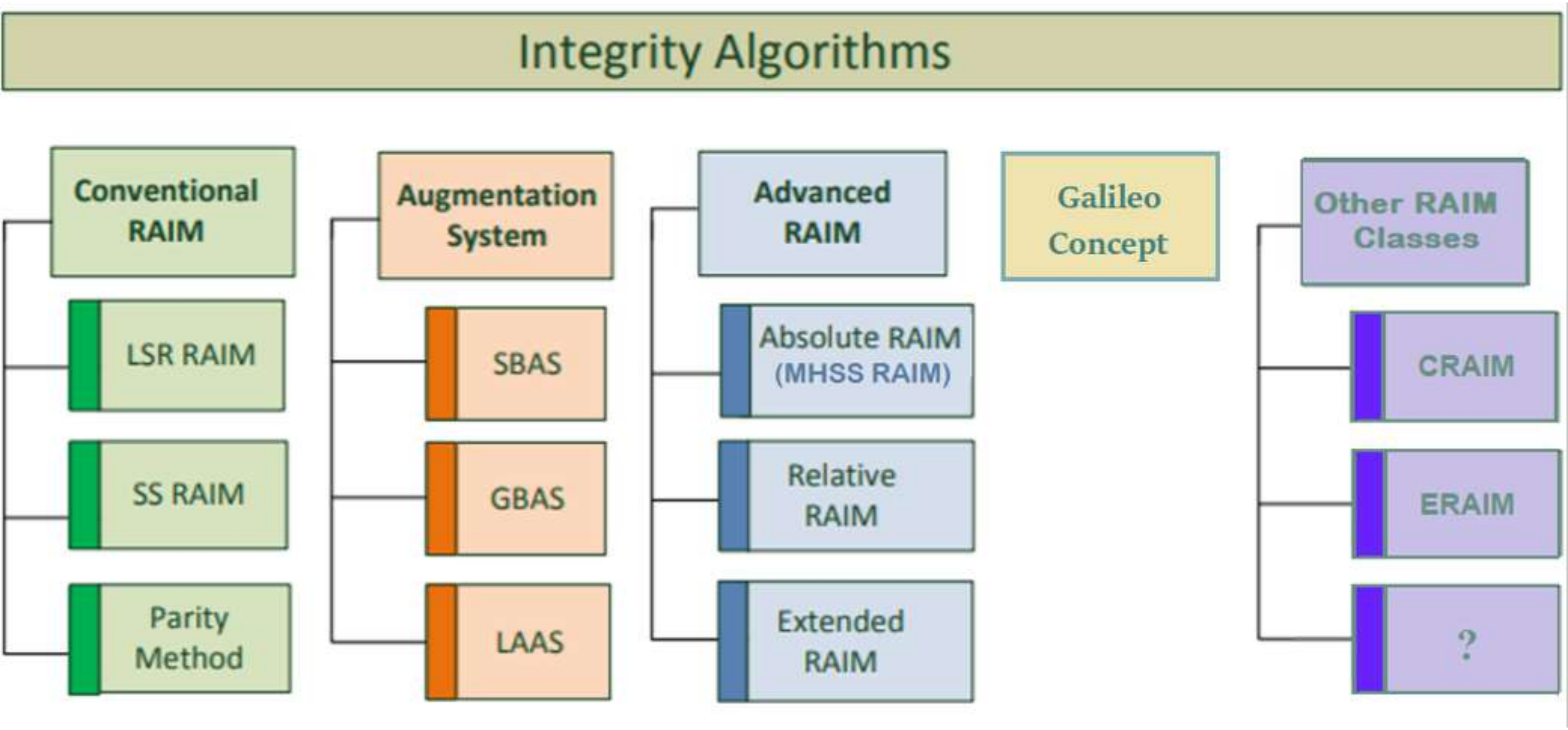
	System Level Parameters		
	Alert Limit (m)	Time to Alarm² (s)	Integrity Risk (per 3 h)
Ocean	25	10	10^{-5}
Coastal	25	10	10^{-5}
Port approach and restricted waters	25	10	10^{-5}

Use Case	Precision	Integrity	Method
Navigation	I'm on the road	10^{-5}	GNSS + DR +Map matching
Traffic Efficiency (V2X)	I'm in the lane	10^{-7}	GNSS (Correction Service) + DR +… Camera?
Autonomous Drive	I'm in this position in this lane	Impeccable	All these, more sensors?

Mapping (AAM)		
Bridge and Tectonic Monitoring for Bridge Safety	0.004 m	30 s
Telecommunications Timing	680 nsec	30 s

Public safety	0.2 – 30 m	2 – 15 s
Collision avoidance	0.2 m	5 s
Connected Vehicle Initiative	0.2	5 s

Integrity systems (Algorithms)



User Level **System Level** **Mixed Level** **System Level** **Mixed Level**

SS RAIM : Solution Separation

RAIM vs ARAIM

	RAIM	ARAIM
Constellation	GPS only	Multi-constellatio GNSS
Frequencies	L1 only	ARAIM utilizes dual frequency signals (L1,E1)/L5,E5)
Usage	Aviation applications	It is under developing to cover the AD (complex environments. Multipath, erroneous clocks (in the case of terrestrial signals of opportunity), spoofing, …)
Error model	Gaussian with zero mean	Other biases are considered
Failure rate	In range of 10^{-4} per hour per satellite	In range of 10^{-5} per hour per satellite

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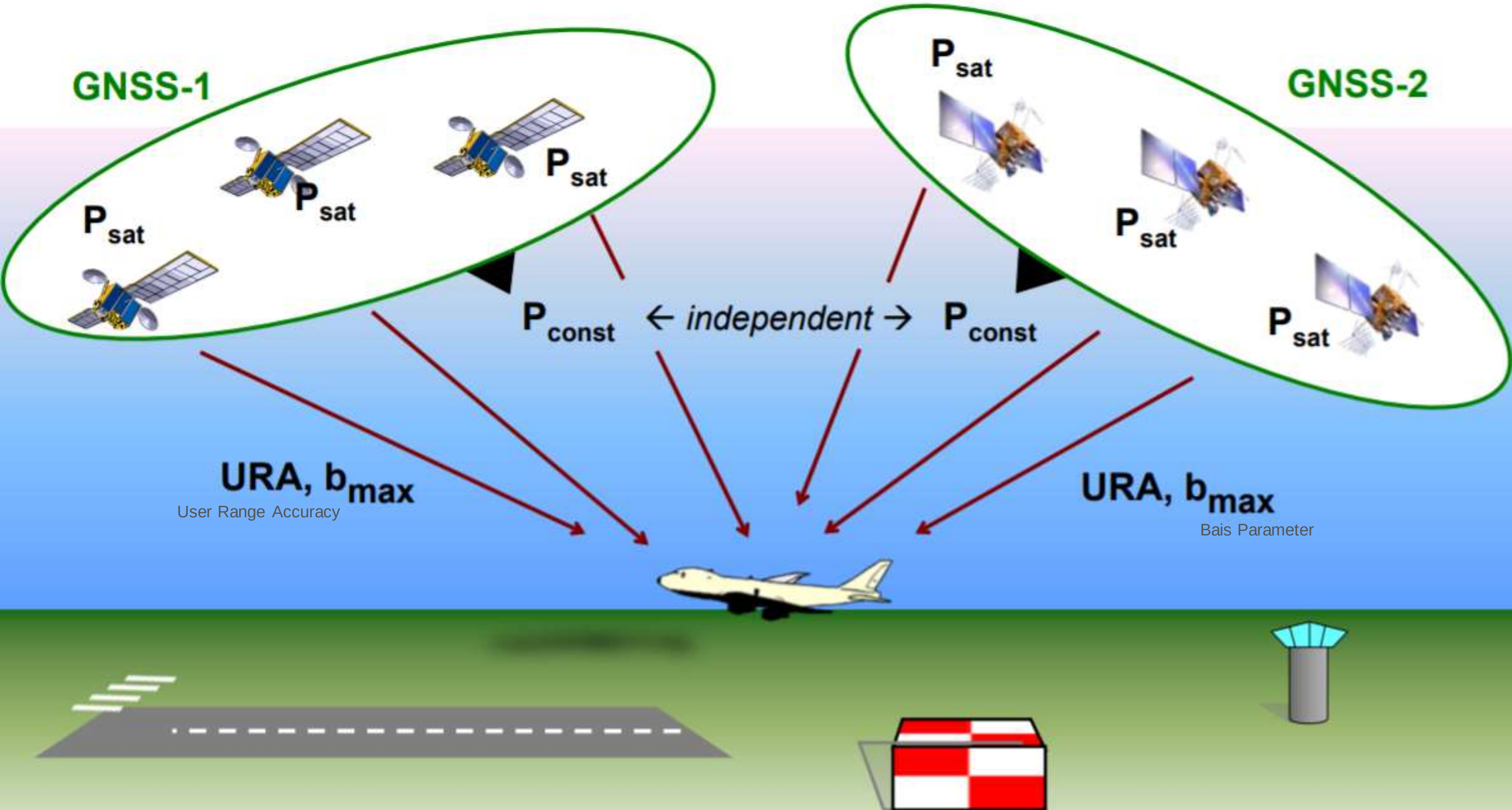
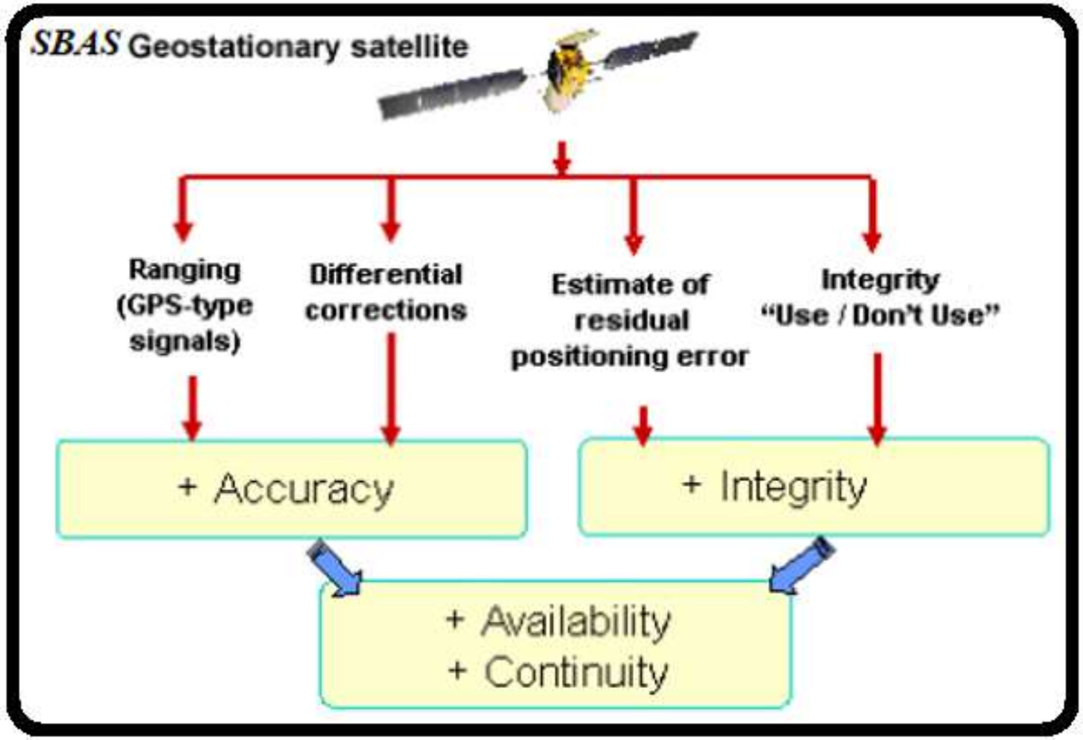
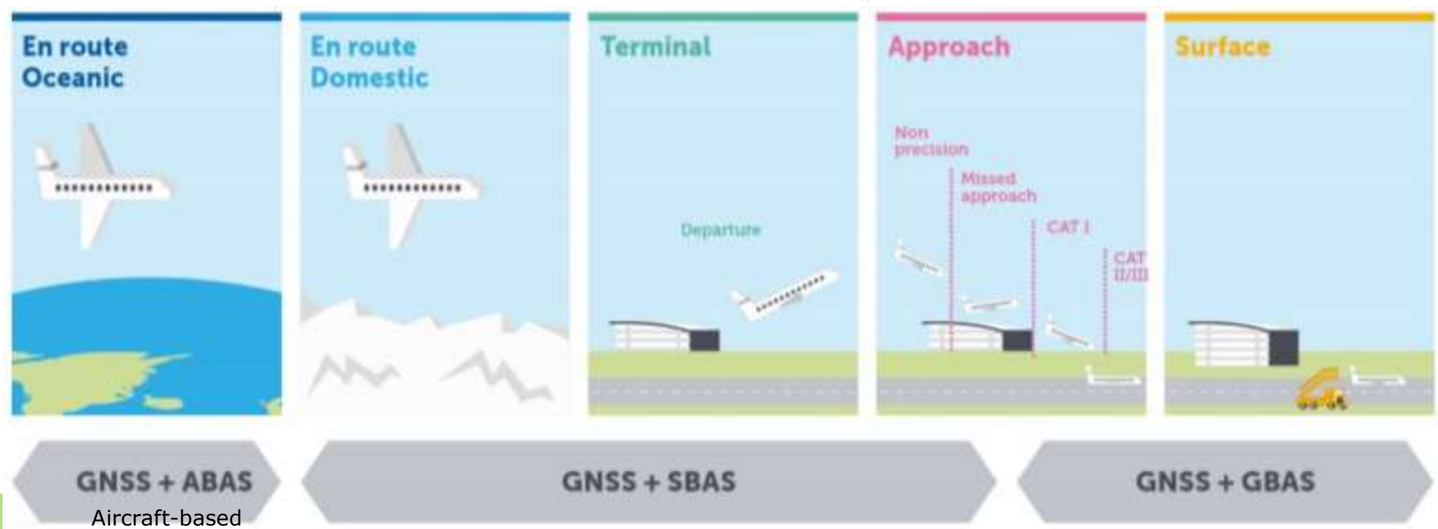
ARAIM Parameters

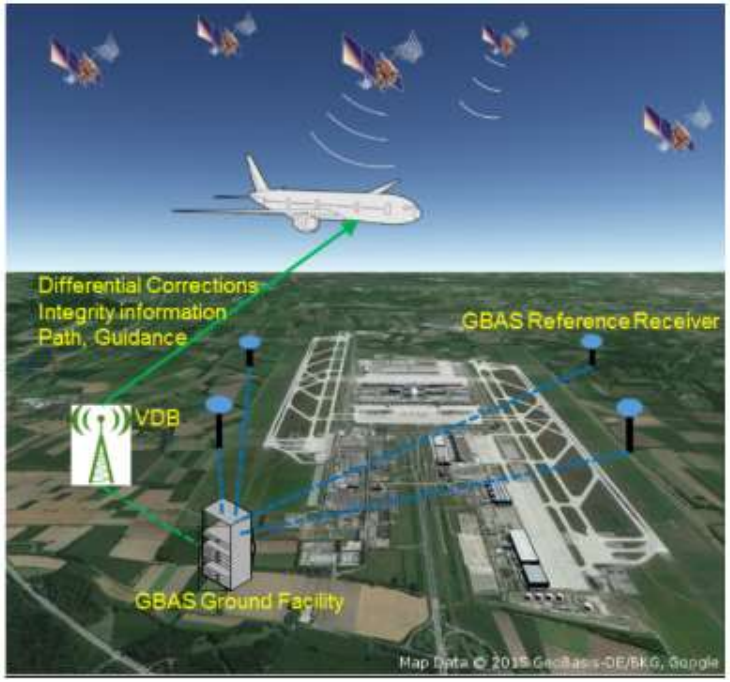


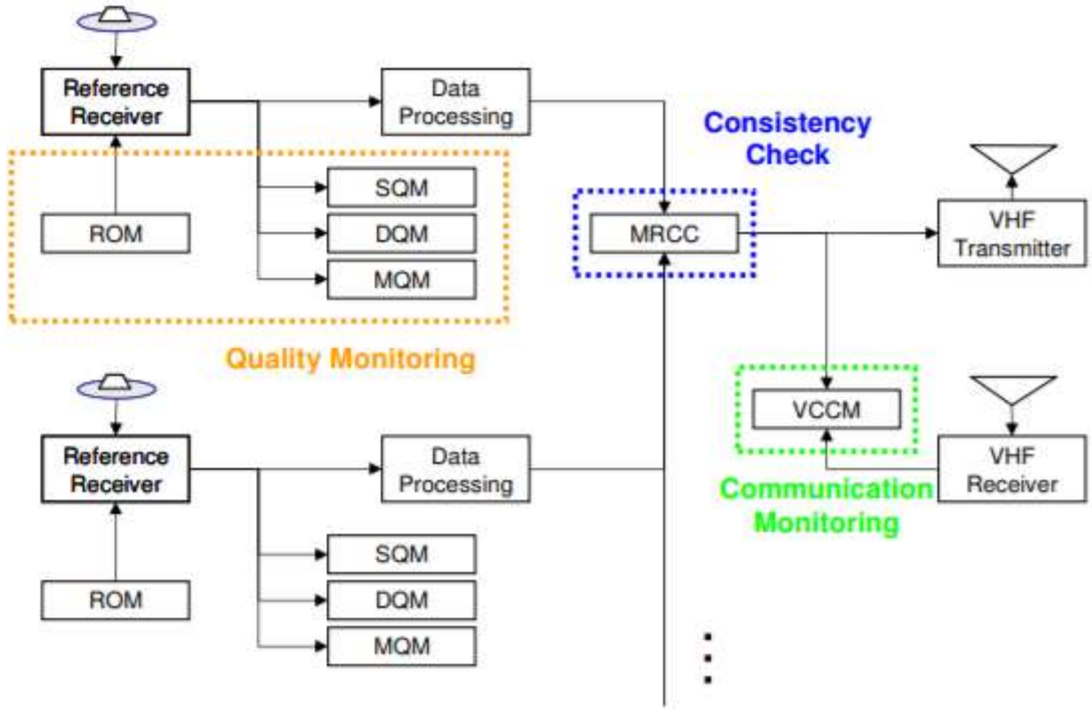
SBAS (EGNOS, WAAS, ….) integrity concept





GBAS Integrity Concept





Based on the information received from the GGF and also based in own data, the aircraft computes HPL and VPL for each epoch (every 0.5 second)

The **Quality Monitoring** function includes four parts:

- **Receiver Operation Monitoring** (ROM)
- **Signal Quality Monitoring** (SQM)
- **Data Quality Monitoring** (DQM)
- **Measurement Quality Monitoring**(MQM)

- **Consistency Check**.

-Communication Monitoring

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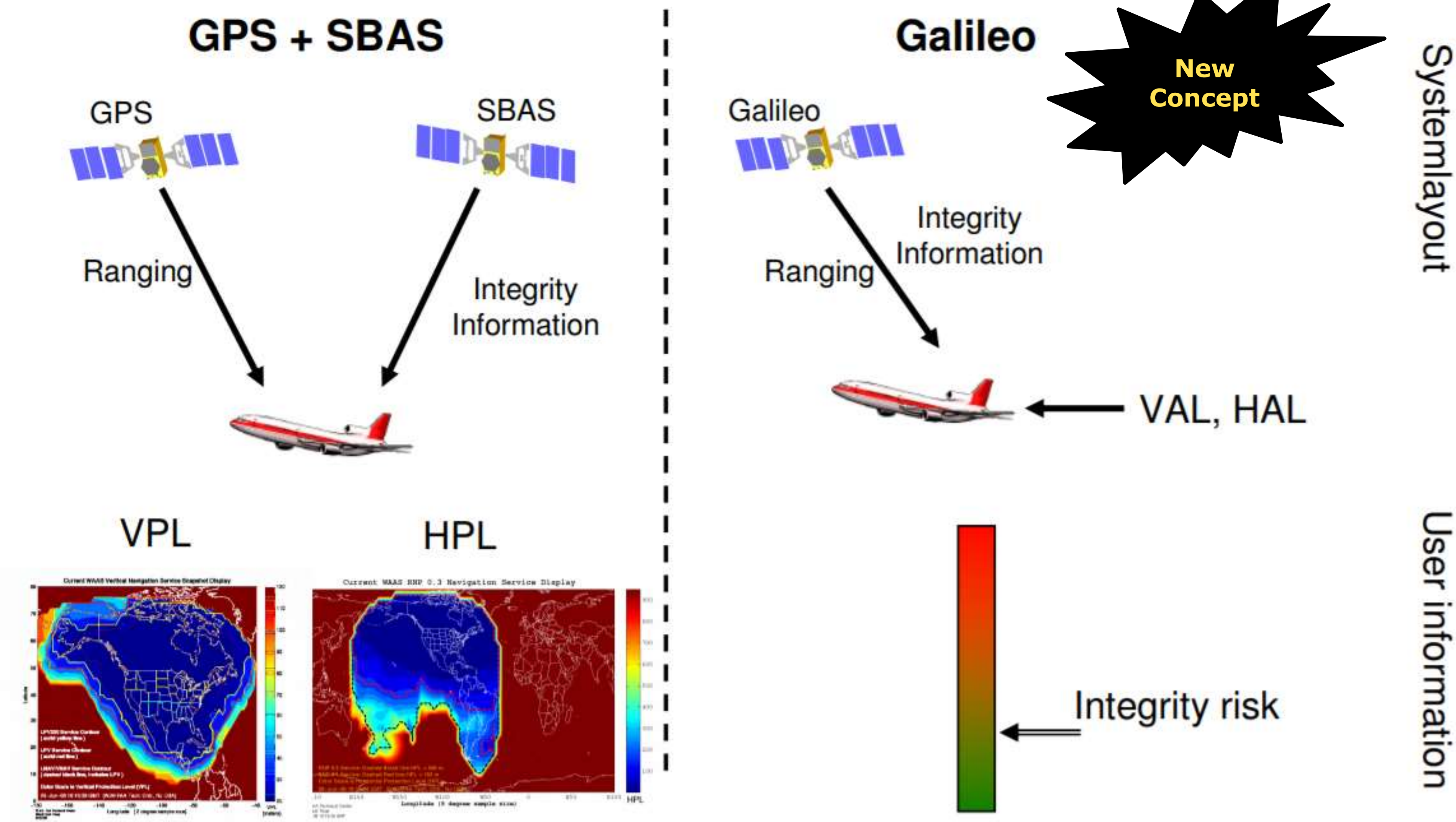
Galileo Concept of integrity

SWEPOS



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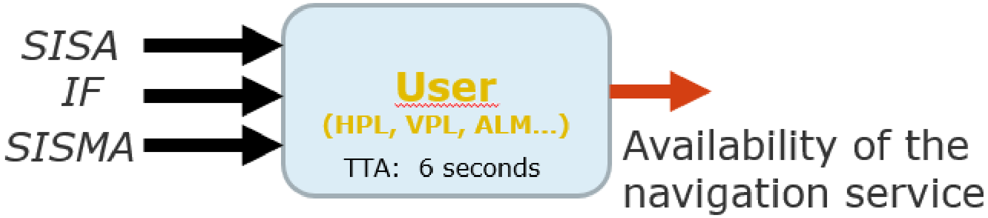
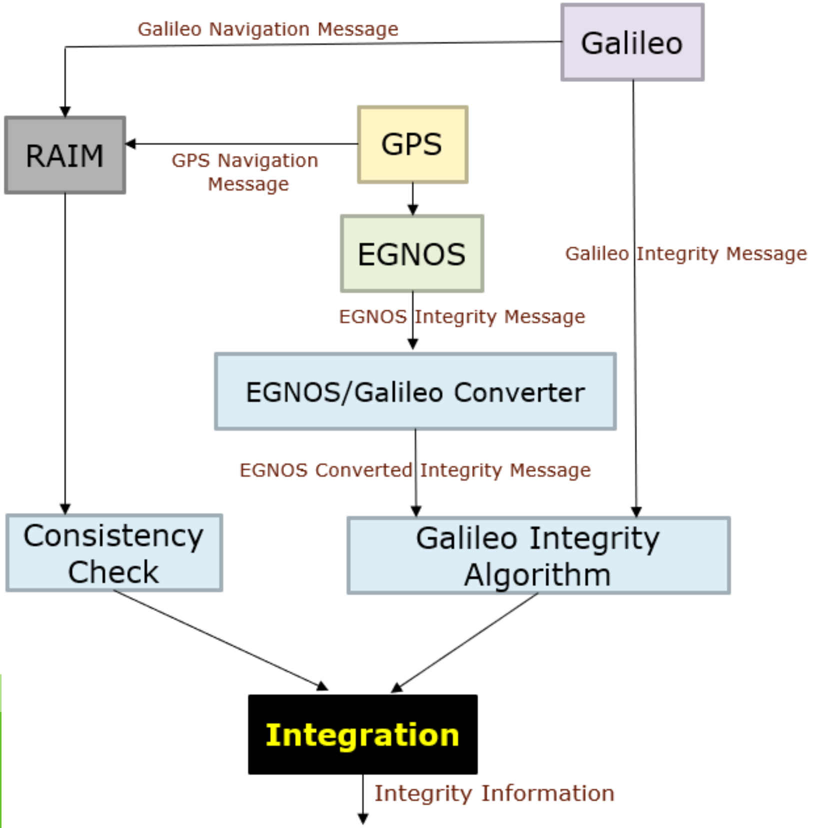
Galileo integrity

Galileo will provide the SOL service through providing 3 elements:

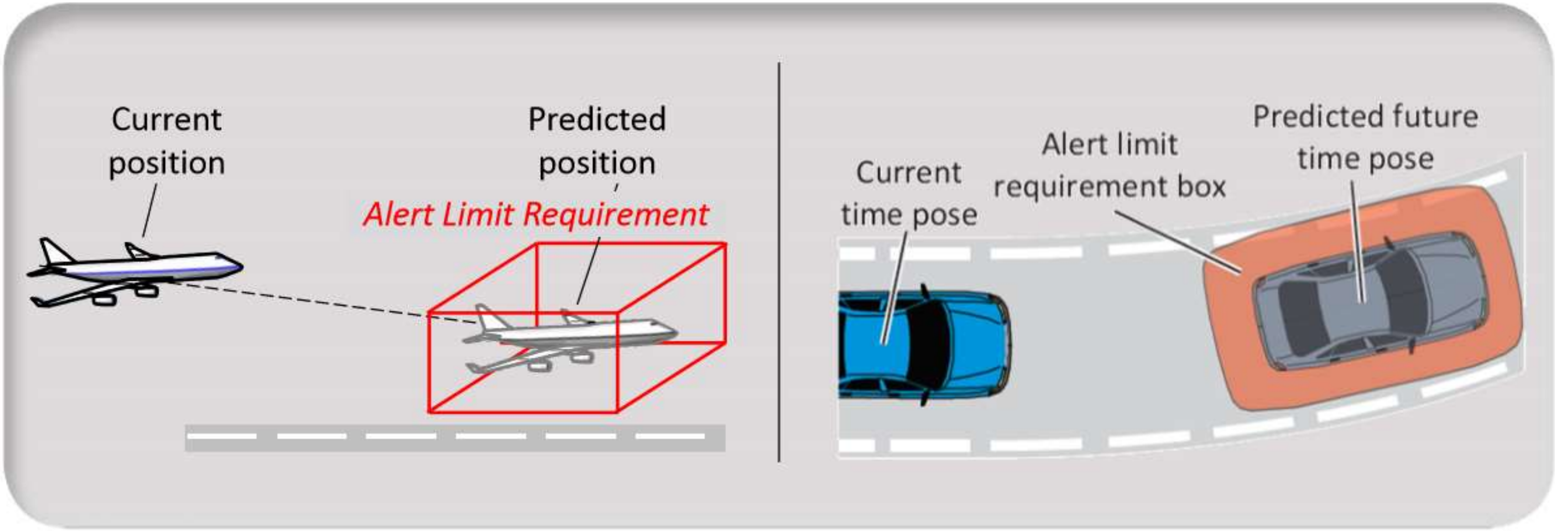
- ***Signal-in-Space Accuracy (SISA)***: Expectation of the errors relative to the SV's clock and ephemerides.
- ***Integrity Flags (IF)***: Warning relative to a satellite that is transmitting a signal with an excessive error. IF is founded on the short term observation of the *clock's variations*, the *ephemeris* and the *RF signals*.
- ***Signal-in-Space Monitoring Accuracy (SISMA)***: Describes the SISE determination quality based on the Galileo Sensor Stations (GSS) observations. SISMA will be broadcast in a shorter time interval of 30 seconds.





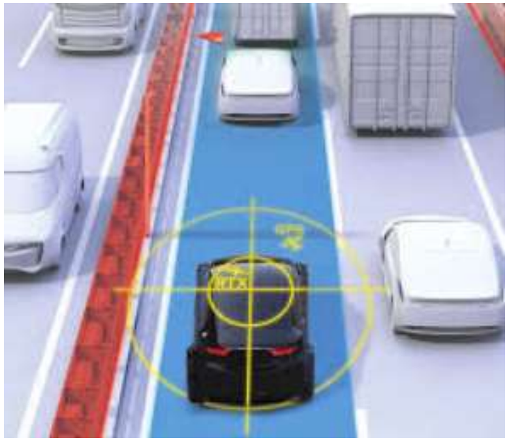
Integrity monitoring (IM) on Land - Vehicle

It is possible to adopt the classic integrity mechanisms, for road application??? And How???



Integrity monitoring (IM) on Land - Vehicle

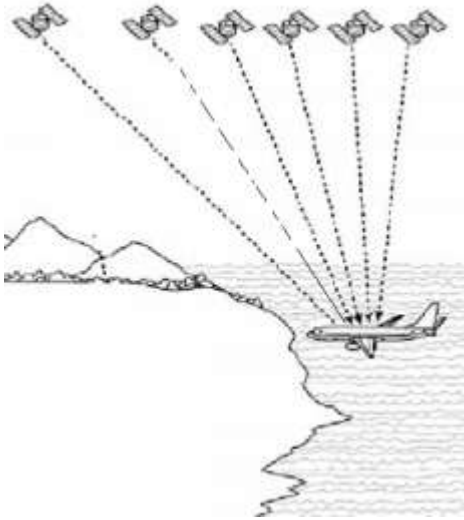
Unfortunately, the same methods (SBAS/GBAS, RAIM, ARAIM, ….) do not directly apply to HAVs (Highly Automated Vehicle), because some differences in the **requirements** and **environments**:



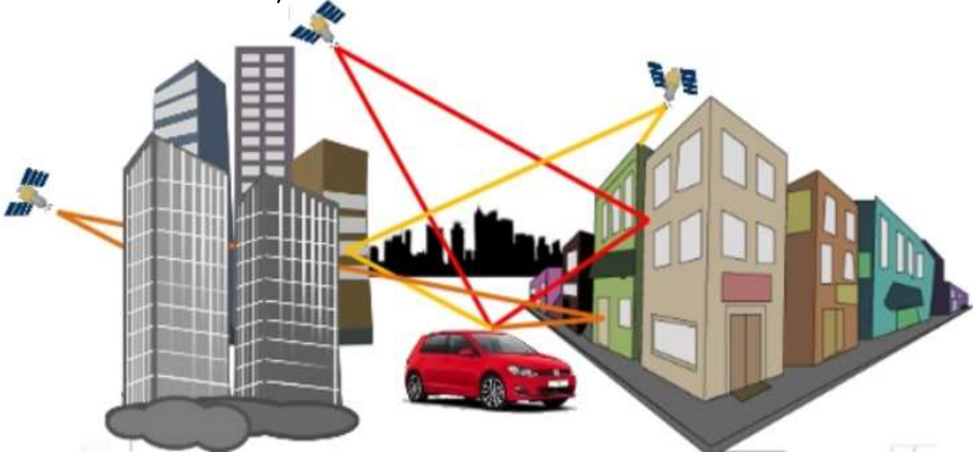
The Requirements

Higher precision/smaller (cm) PLs are required. As such level of accuracy is considered unattainable with Aviation, ITS applications are foreseen to be relying on SBAS, RTK or PPP techniques. These methods bring with them a new set of specific vulnerabilities. As example, in case carrier observations are to be used, cycle-slip monitoring shall be included, as well as IM for AR

The environment



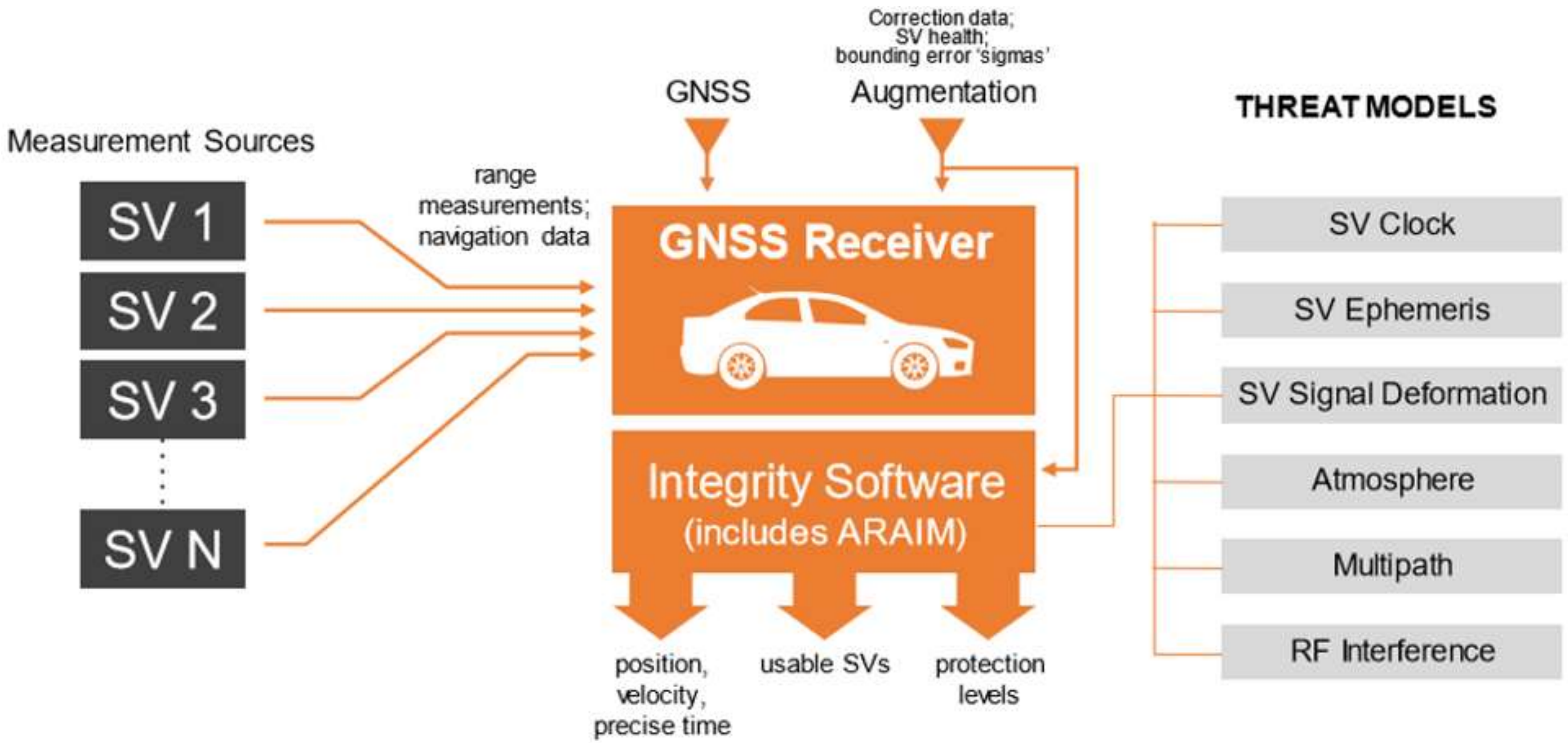
Land users are often located in urban environment (high-rise buildings), And here, GNSS observations are highly more likely to be affected by multipath and Non-LOS (NLOS). Furthermore, the urban environment brings extra vulnerabilities linked to the higher risk of interference, Changing environment, environmrntal diversity, other road users, large numeber of car manufacturers, …



Integrity monitoring (IM) on Land - Vehicle

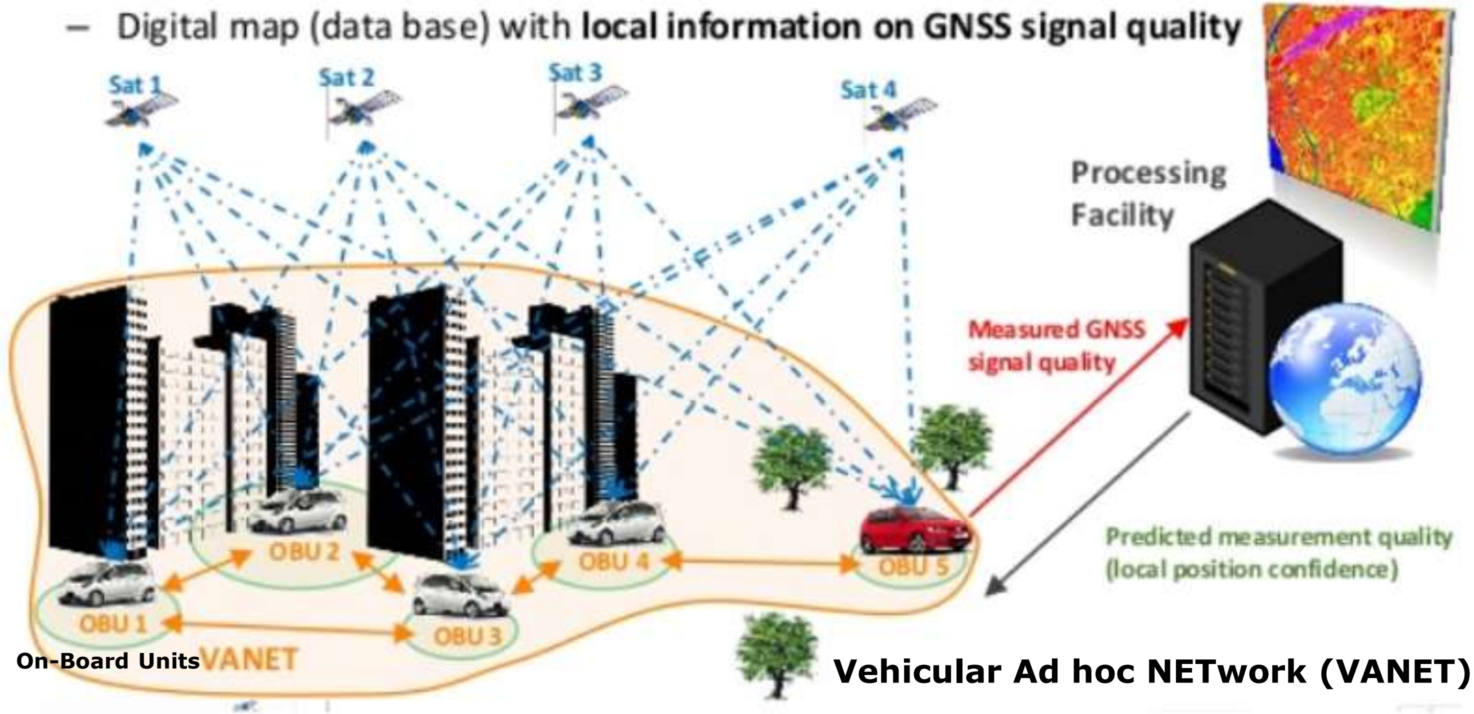
Proposals:

PL will be calculated in real-time and will be provided to the vehicle guidance controller at a 1 Hz rate or faster (with different required hazard rates)



Local GNSS Integrity Principle

- **Centralized processing** of GNSS measurements:
  - Collection of measurements taken by many cars in a certain area at certain times
  - Digital map (data base) with **local information on GNSS signal quality**



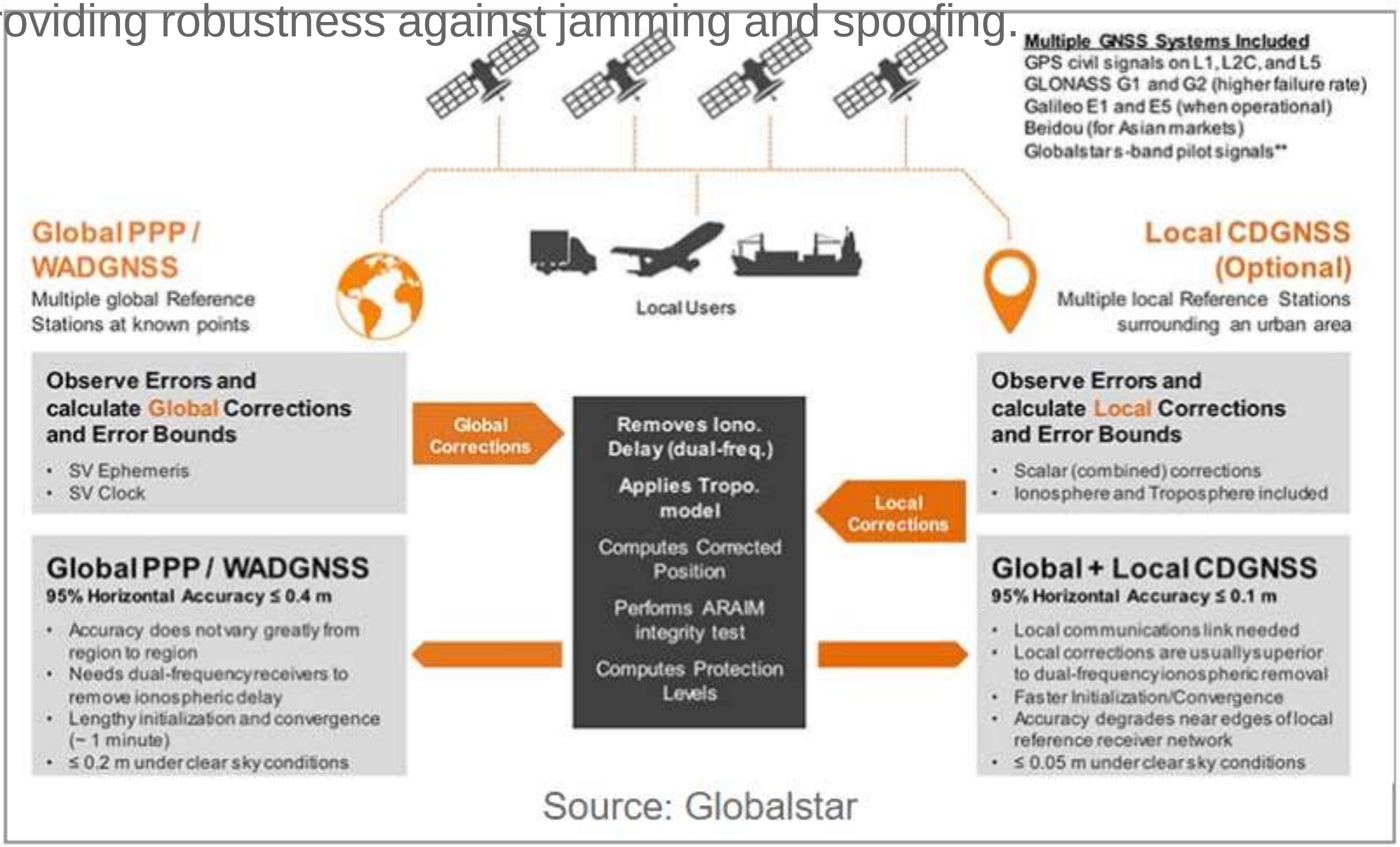
  - **Cars used as sensors** for signal quality assessment using mass-market receivers
  - **GNSS observations** taken on board of the cars are shared by means of **communications**
  - **Collaborative monitoring** of GNSS signals in urban scenarios
    - Spatial/temporal characterization of <u>**local**</u> **signal degradations**

- **Computation of** <u>"Local Protection Levels" ellipses</u>

Enhanced navigation, robustness, safety for autonomous vehicles

Globalstar is developing a connected car program for continuous, worldwide service to vehicles. This combines PPP corrections provided globally (via LEO satellites) with local-area corrections (via LTE) in urban areas for connectivity anytime, anywhere. Both signals are broadcast at 2.4 GHz and include:

- Pilot channels used for ranging,
- Augmenting GNSS ranging,
- Providing robustness against jamming and spoofing.



Source: Globalstar

Questions?