ERSAT EAV

"ERTMS on SATELLITE Enabling Application & Validation"

ERSAT EAV Achievements & Roadmap

The High Integrity Augmentation Architecture

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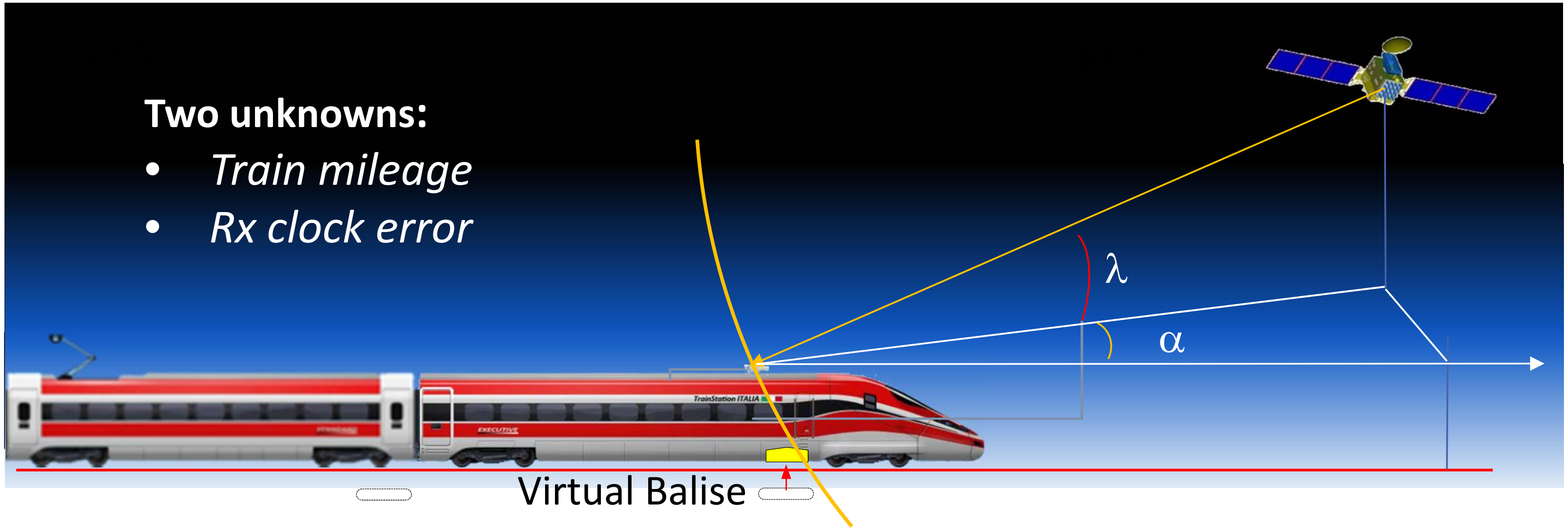
GNSS-BASED SERVICES FOR TRAIN CONTROL

- GNSS based train location determination can be considered a disruptive technology.
- It will succeed in replacing the current technologies based on balises and track circuits if and only if it will be cost-effective.

THR $\leq 10^{-9}$/h

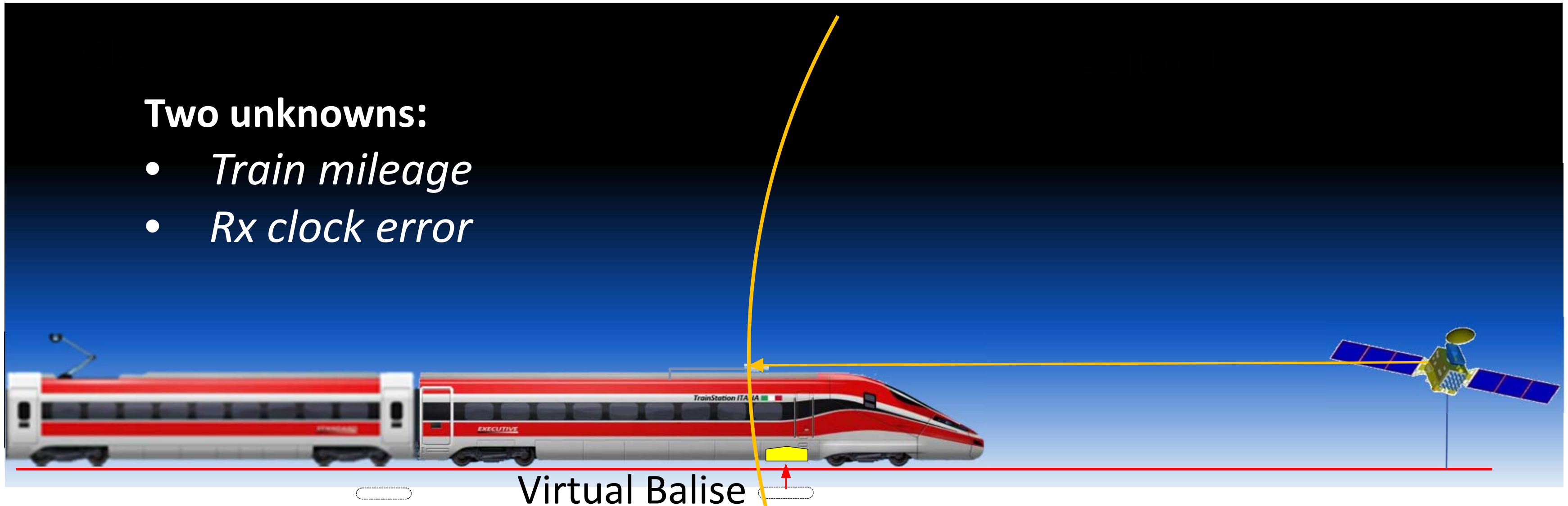
Functionality	Current EU Technology (ERTMS)	SIS Integrity Monitoring	Augmetation	**Accuracy**
Train Location Determination • Single track	Based on Balise	**X**	**X**	Medium
Train Location Determination • Multiple tracks	Based on Balise, Track Circuit	**X**	**X**	Medium, High
Train Integrity	Track Circuit + On Board Circuitry	**X**		High

GNSS BASED TRAIN LOCALIZATION



- The Train location is given by the intersection of the spheres centered on visible satellites and the railway track

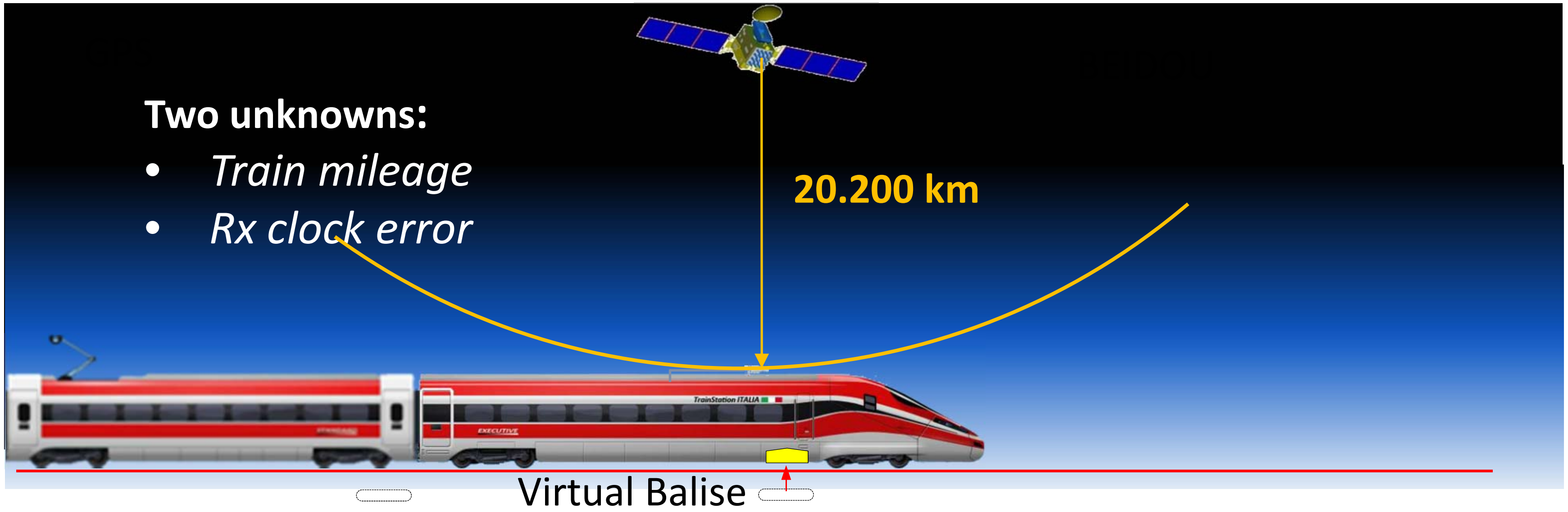
GNSS BASED TRAIN LOCALIZATION



- The information carried by each satellite with respect to **the train mileage** depends on the relative geometry.

- BEST CASE:
- *Satellite lying on track axis*

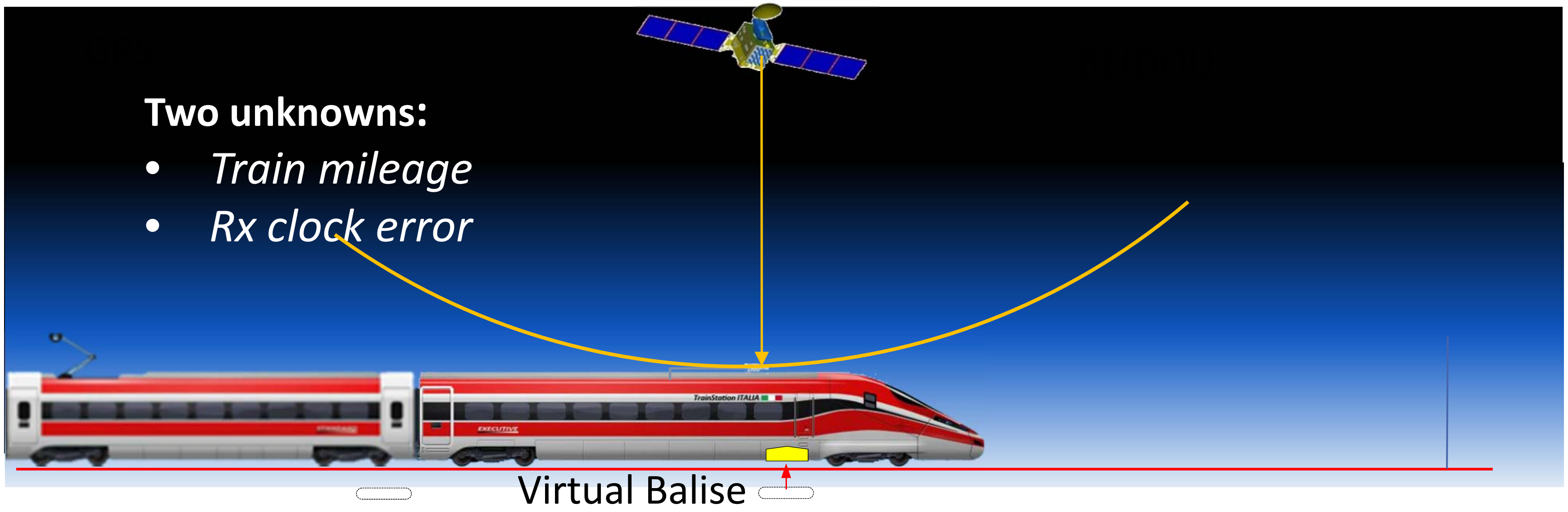
GNSS BASED TRAIN LOCALIZATION



- The information carried by each satellite with respect to **the train mileage** depends on the relative geometry.

- WORST CASE:
- *Satellite Line of Sight orthogonal to the track axis*

GNSS BASED TRAIN LOCALIZATION



- The information carried by each satellite with respect to **the train mileage** depends on the relative geometry.

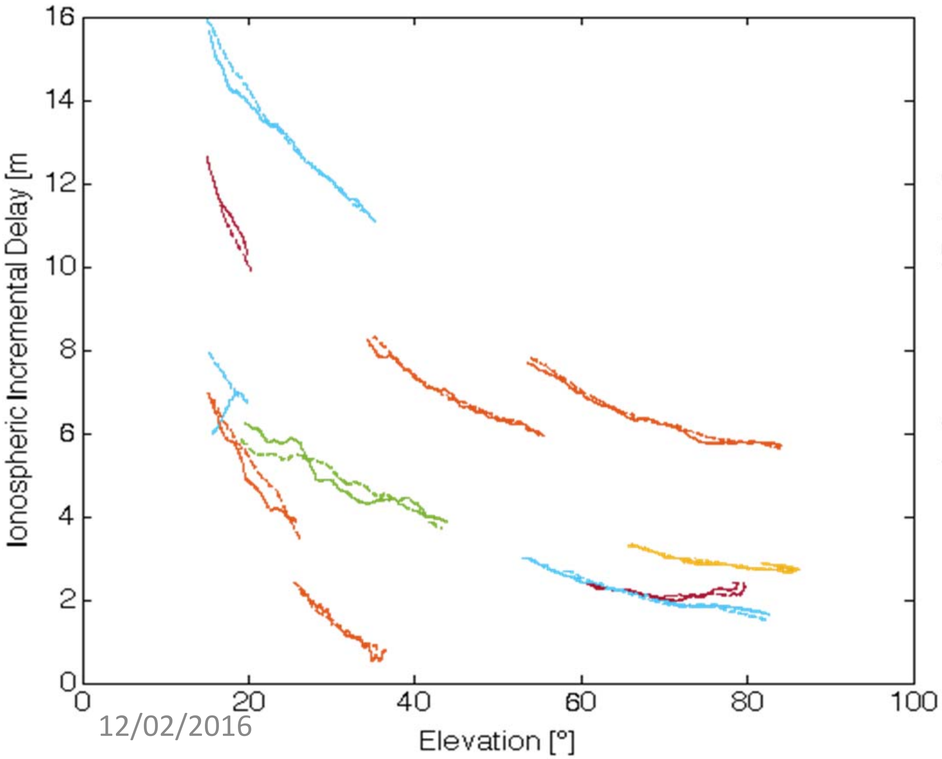
Error Sources
Satellite ephemerides and clock errors
SIS distortions
Ionospheric incremental delay
Tropospheric incremental delay
Rx noise, multipath, RFI

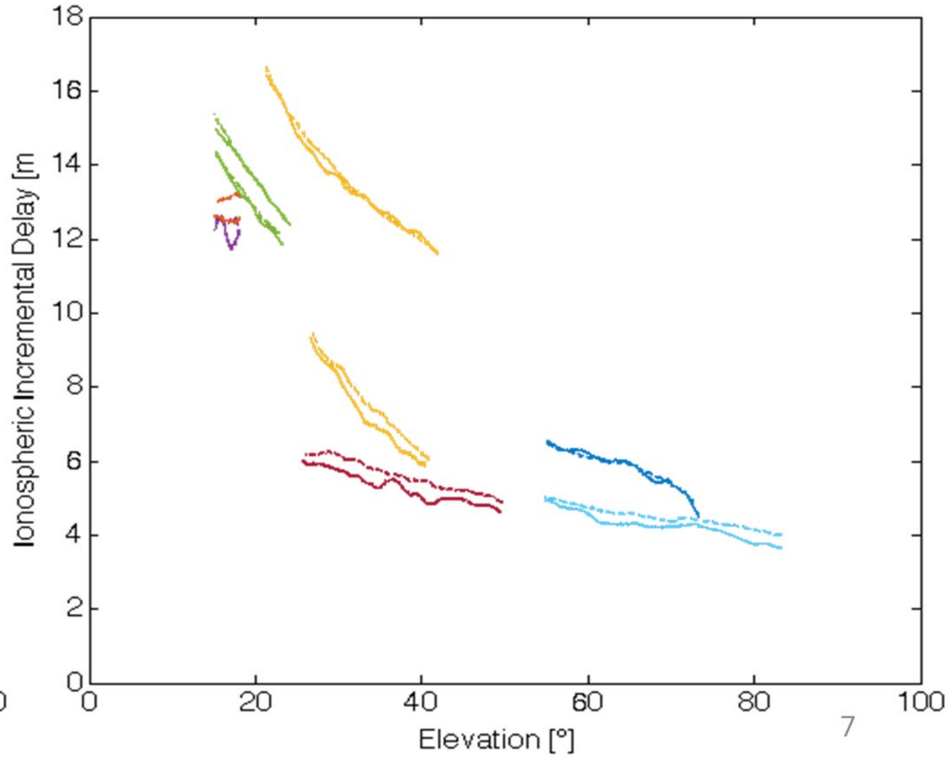
IONOSPHERIC INCREMENTAL DELAY (GPS L1 – L2)

- *It can determined by combining the pseudorange measured at two different frequencies*

Usual conditions

Geomagnetic Storm
(17/3/2015 14.00 UTC)



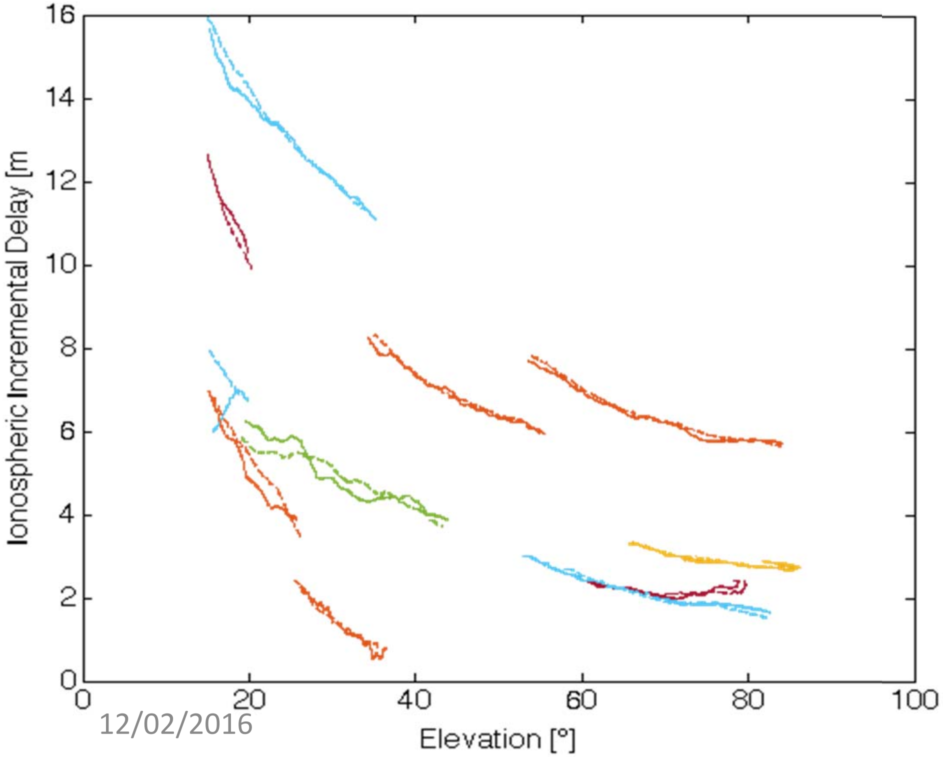


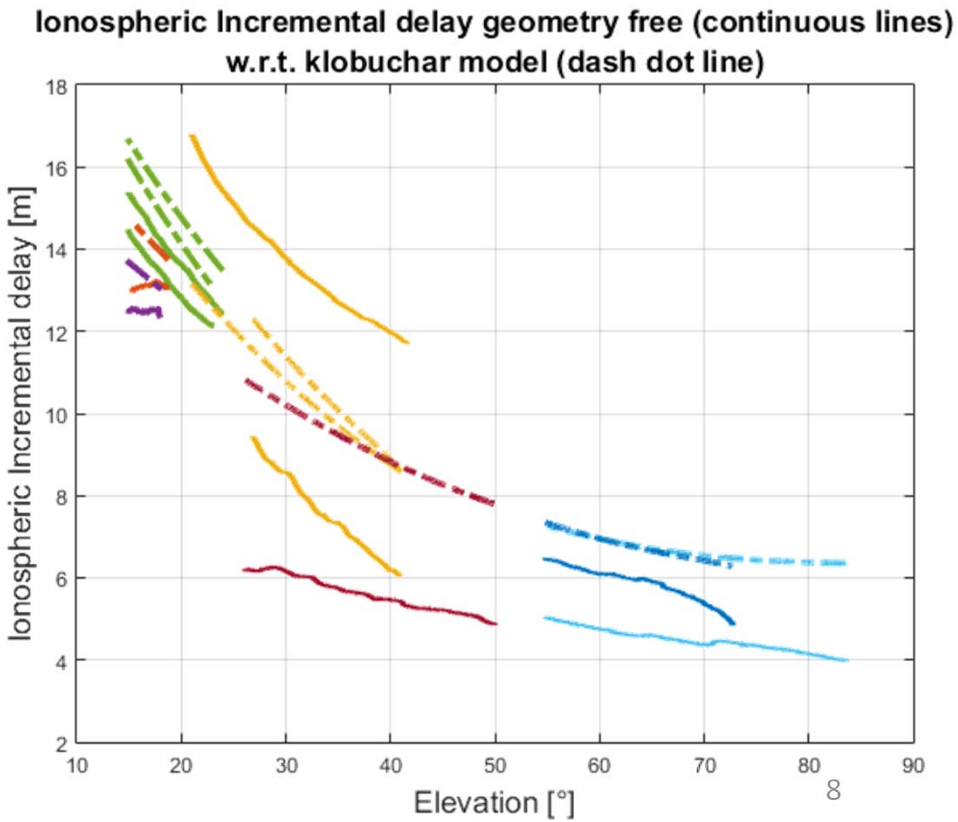
IONOSPHERIC INCREMENTAL DELAY (GPS L1 – L2)

- *Ionospheric corrections included in the Navigation Message may be inadequate*

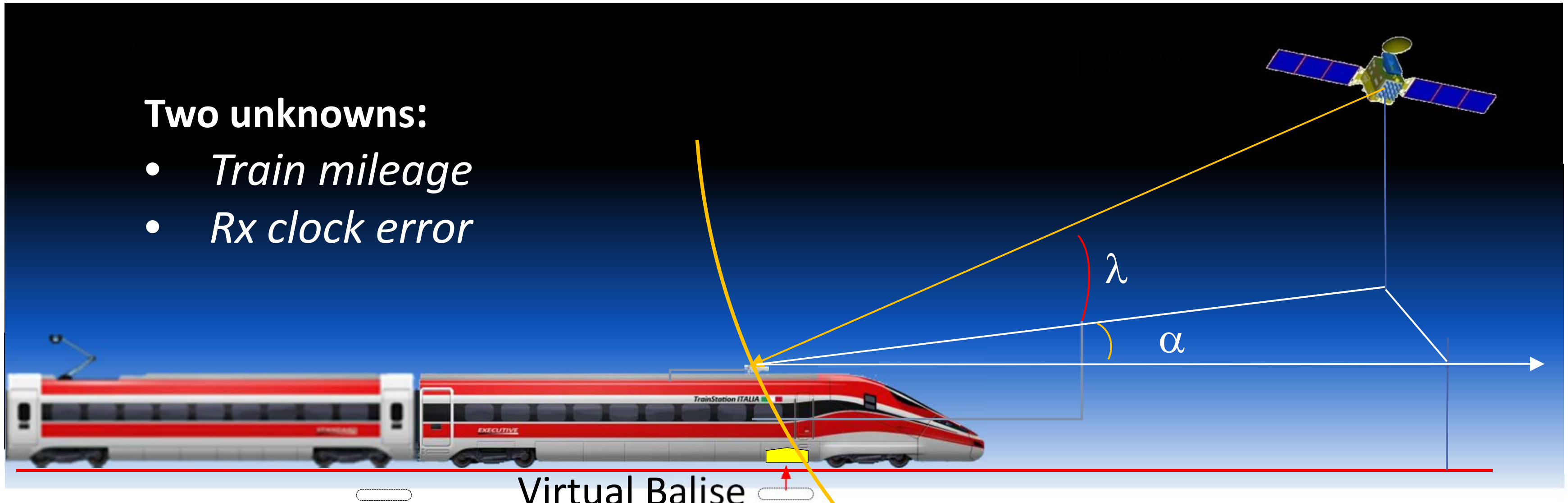
Usual conditions

Geomagnetic Storm
(17/3/2015 14.00 UTC)

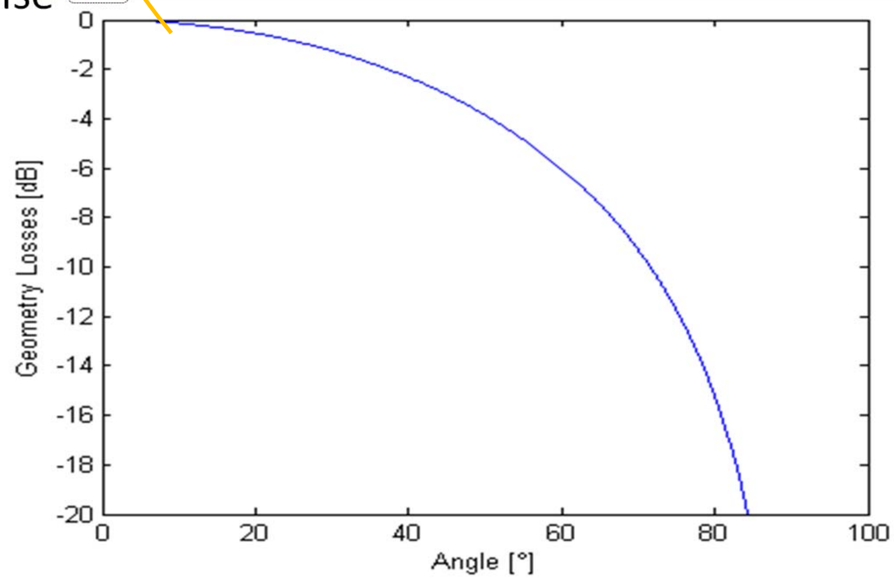




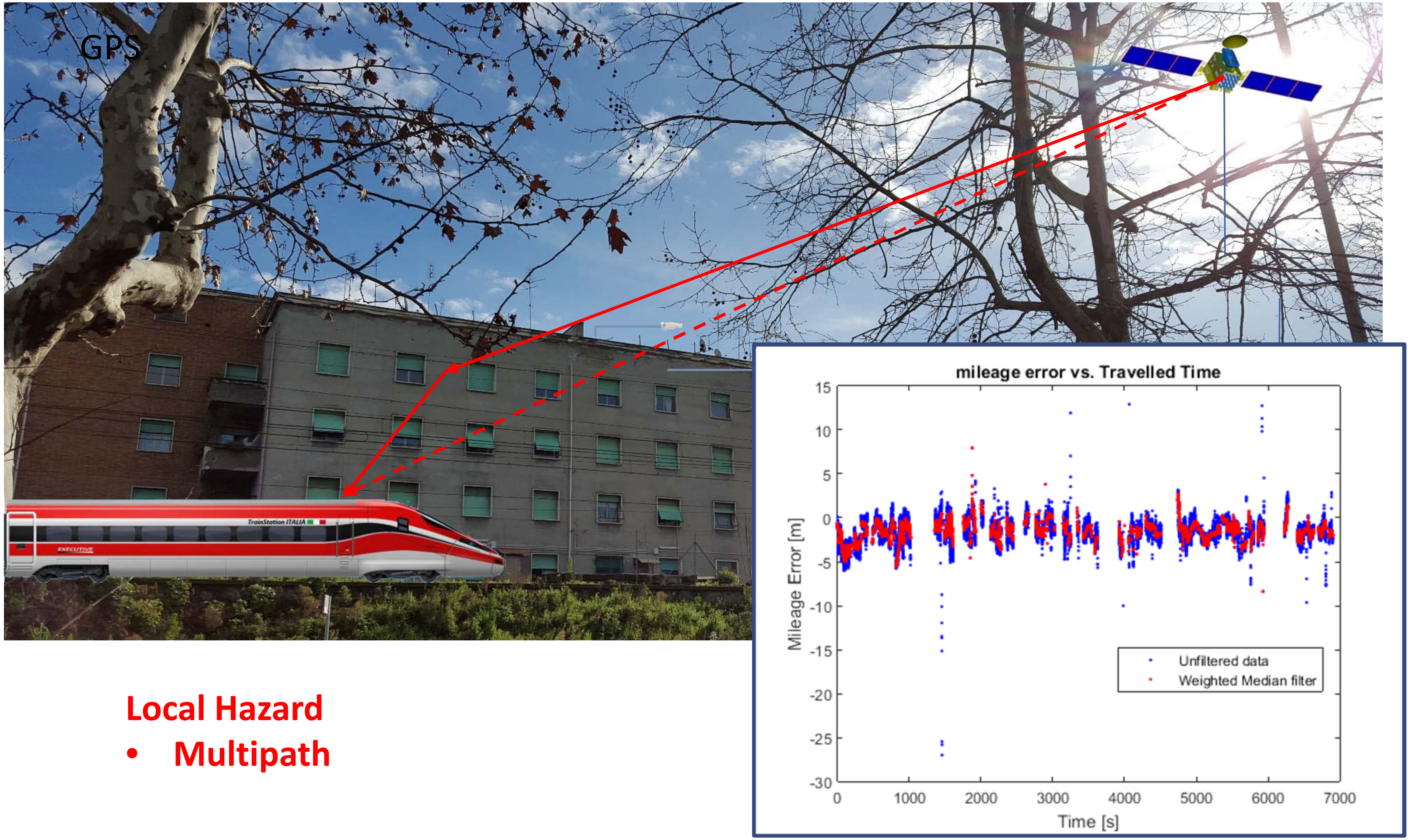
GNSS BASED TRAIN LOCALIZATION



- The information carried by each satellite with respect to **the train mileage** depends on the relative geometry.
- Satellite off-axis accountable as SNR additional loss



GNSS BASED TRAIN LOCALIZATION

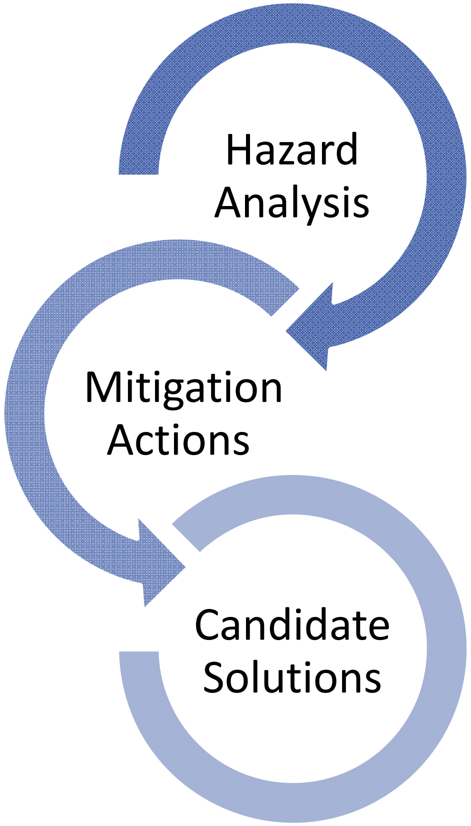


Local Hazard

- **Multipath**

OVERLAY ARCHITECTURE

Selection of candidate solutions concerning both augmentation and integrity monitoring infrastructures, and On Board Units starts from the mitigation actions related to the hazards identified during the Hazard Analysis



Hazards	Mitigations
Clock runoffs	SBAS & LADGNSS
Ephemeris Faults	SBAS & LADGNSS
Ionospheric storms	LADGNSS (multifrequency)
Signal Distortions	SBAS & LADGNSS
Constellation Rotations	SBAS & LADGNSS
Multipath	Train Autonomous Integrity Monitoring
Jamming, Spoofing	DBF + High Resilience DSP Train Autonomous Integrity Monitoring

ERSAT EAV HIGH INTEGRITY AUGMENTATION ARCHITECTURE

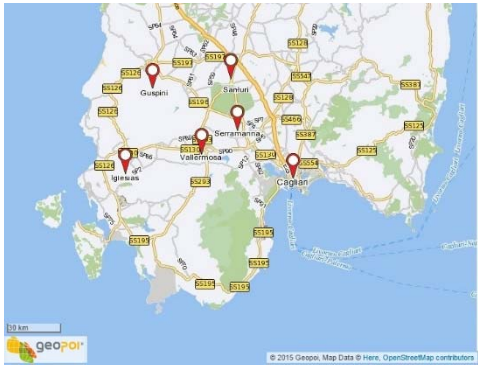
DRIVERS

ERTMS (SIL-4) requirements — Cost-effectiveness — Readiness

Shared with other services (Avionics, Automotive)

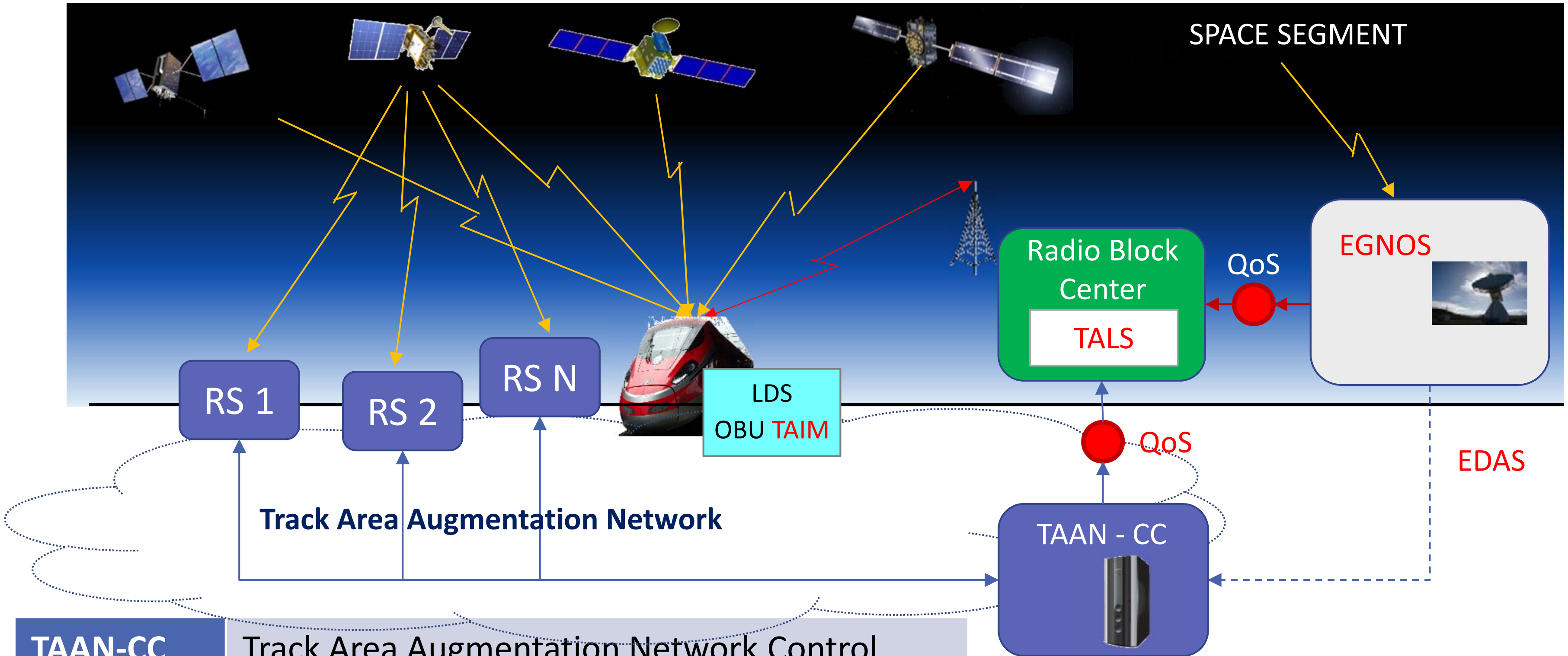
Two tiers Multiconstellation System

- **1st tier:** Wide Area Differential Corrections and RIMS raw data trough dedicated link (EGNOS in EU, WAAS in U.S.A.)
- **2nd tier:** Track Areas Augmentation Network (TAAN) based on (low cost) COTS components



Health status of the 2nd tier as well as the integrity of the GNSS SIS is computed by joint processing of 1rst tier Wide Area Differential Corrections and 2nd tier RIM station data

ERSAT EAV HIGH INTEGRITY AUGMENTATION ARCHITECTURE

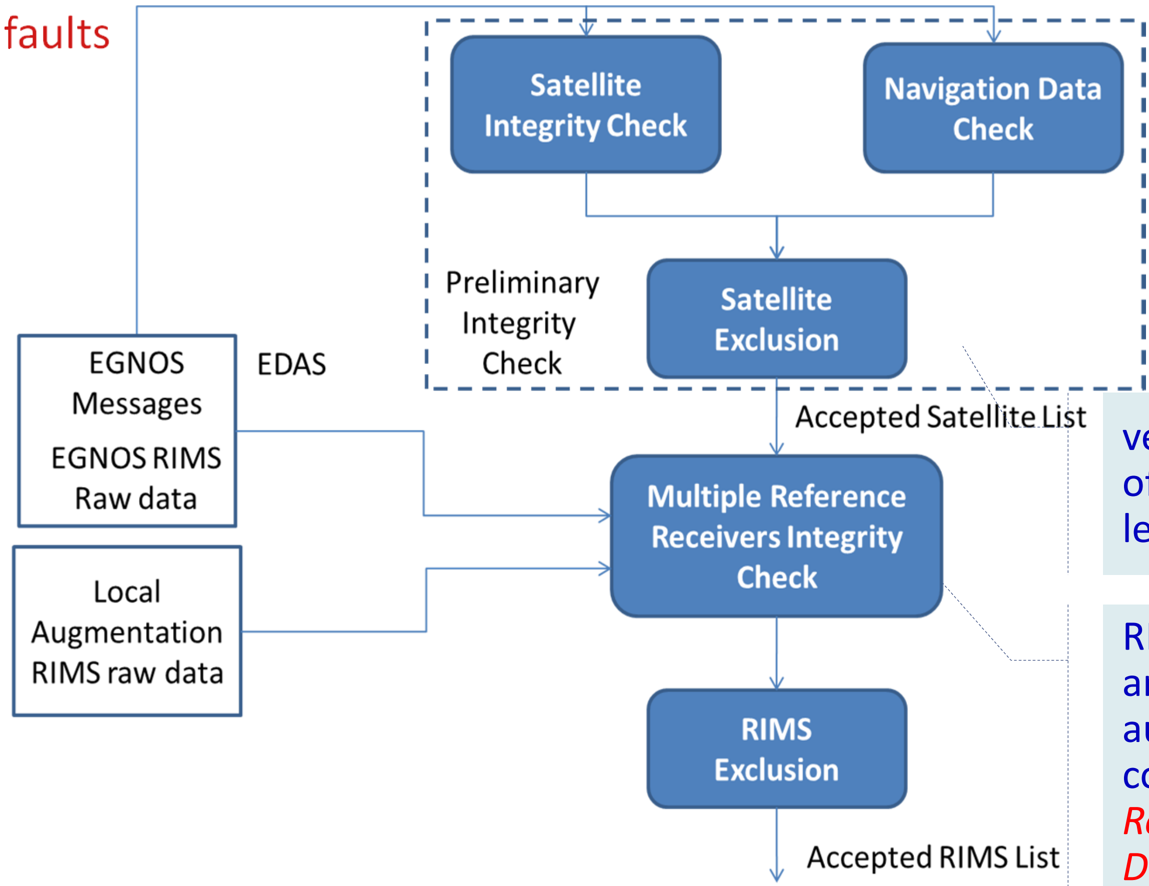


TAAN-CC	Track Area Augmentation Network Control Center
TALS	Track Area LDS Server
RS	Reference Station
EDAS	EGNOS Data Access Service
LDS OBU	Location Determination System On Board Unit

ERSAT EAV 2-tier Local Integrity Function

– **Fault Detection and Exclusion**

- single satellite faults
- constellation faults
- RIM faults



verifies health status of each SIS at RIM level.

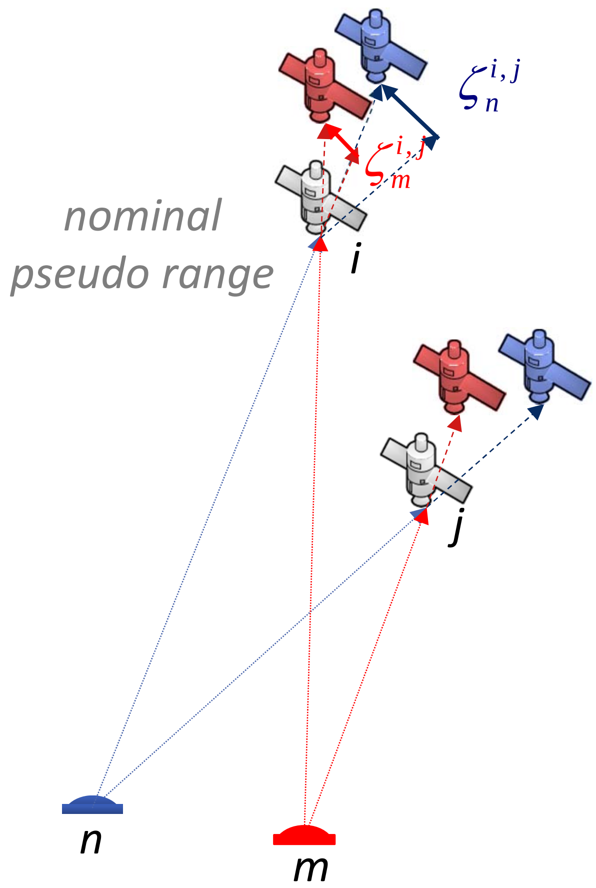
RIM Faults detection and exclusion from augmentation computation *Residual Double Differences*

Multiple Reference Receivers Integrity Check

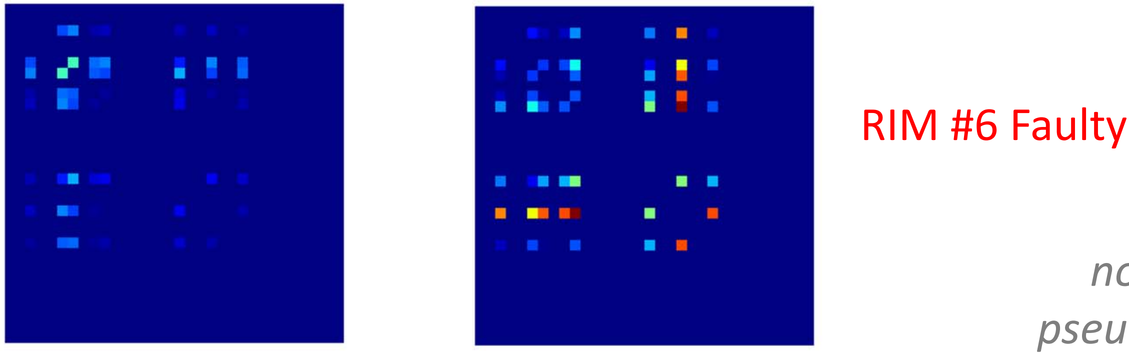
- For each RIM the Multiple Reference Receivers Integrity Check is performed based on statistics derived from the residual Double Differences with respect to raw data provided by the RIMs of the 1rst tier.

- *It is assumed to be negligible the probability that 1rst tier RIM is faulty when declared as healthy.*

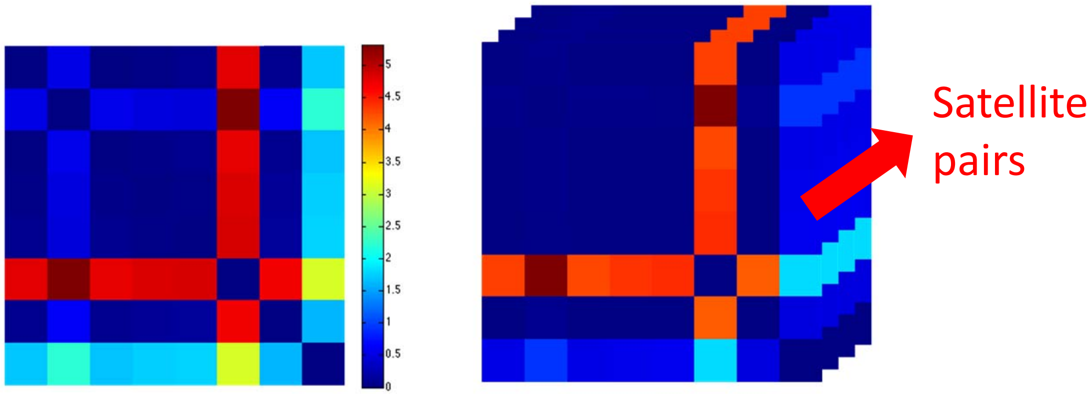
- The procedure can be extended to autonomous local augmentation systems.
  - In this case statistics derived from the Double Differences computed among the 2nd tier RIMs only are employed.



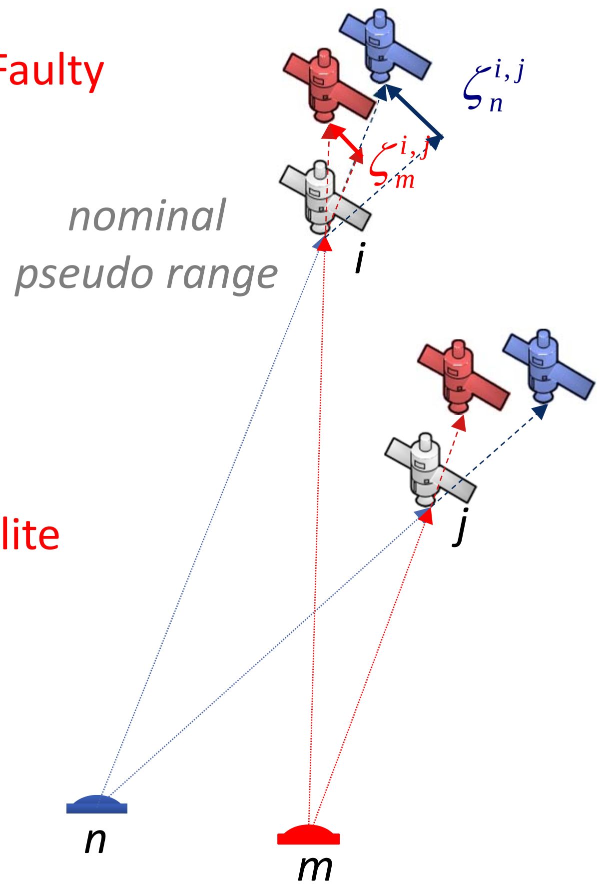
Multiple Reference Receivers Integrity Check



$\left|\zeta_1^{i,j}\right|$ $\left|\zeta_6^{i,j}\right|$



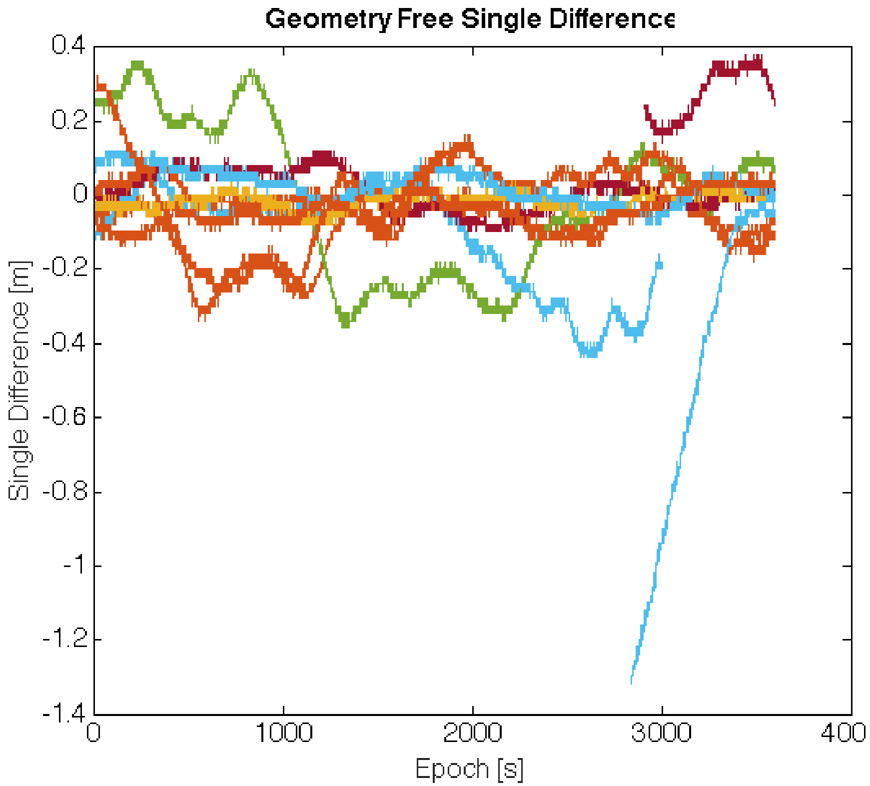
$\left|\xi_{n,m}^{9,20}\right| = \left|\zeta_n^{9,20} - \zeta_m^{9,20}\right|$ $\left|\xi_{n,m}^{9,20}\right|^2 = \left|\zeta_n^{9,20} - \zeta_m^{9,20}\right|^2$

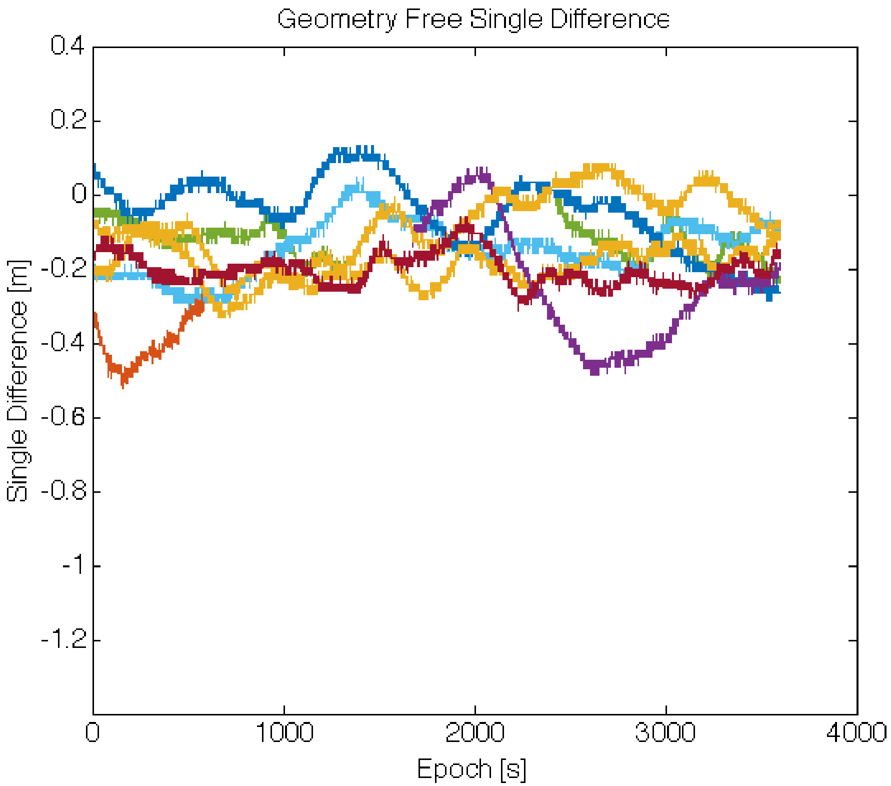


Experimental Results (GPS L1 – L2)

Usual conditions

Geomagnetic Storm
(17/3/2015 14.00 UTC)





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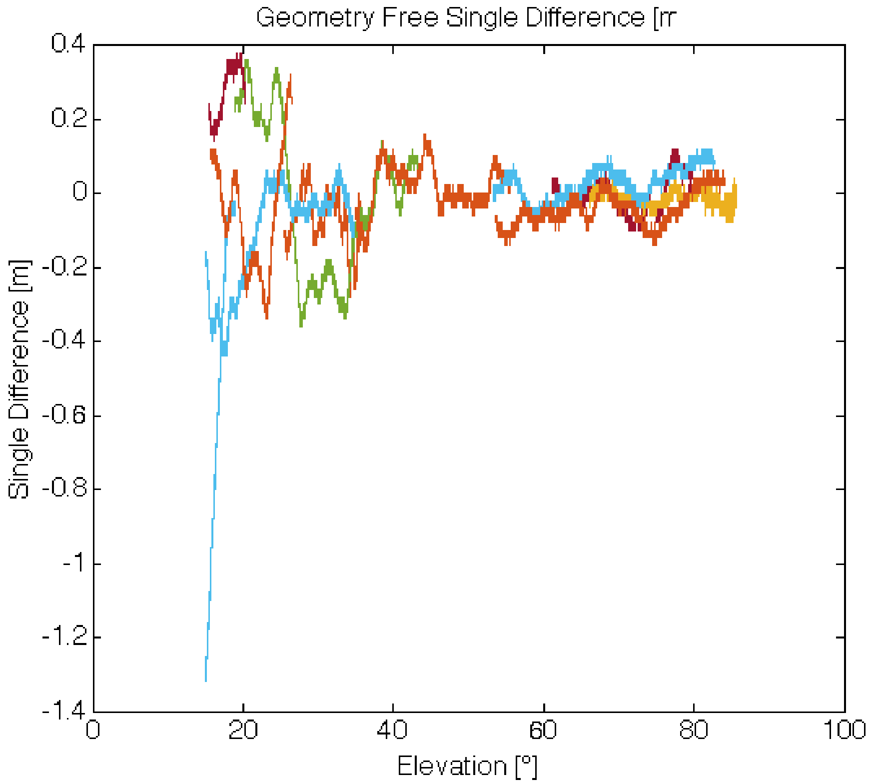
Usual conditions



Geomagnetic Storm
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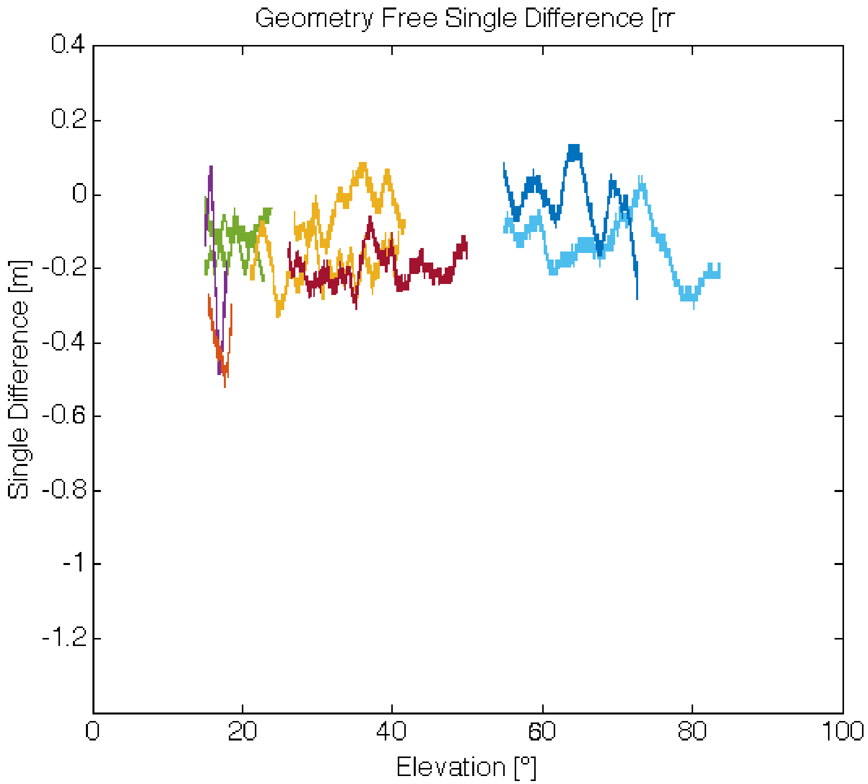
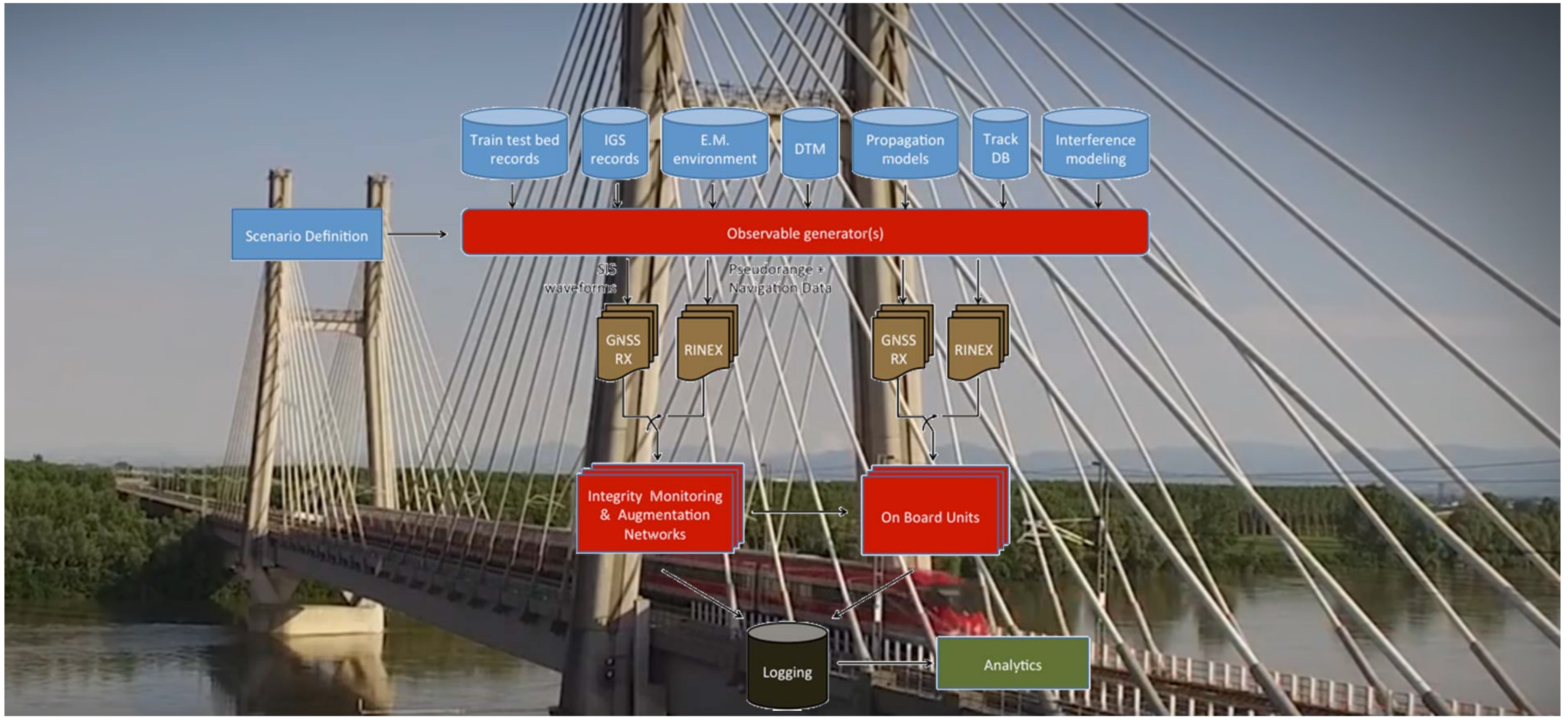


PERFORMANCE ASSESSMENT: THE VIRTUALIZED TESTBED

•Assessing the performance of a Safety of Life system is a rather challenging task due to the fact that very small probabilities are involved.

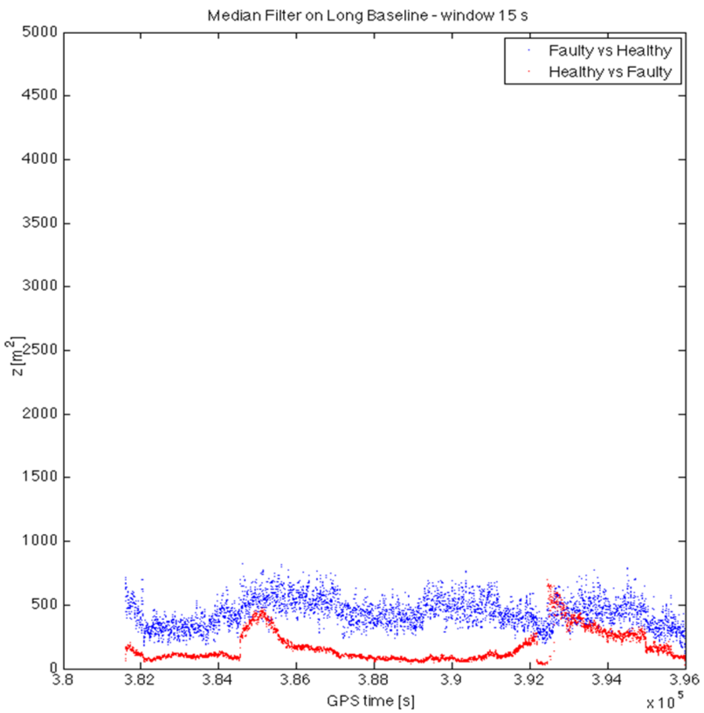
•Approach: virtualized testbed, with

- rich sets of data collected in a real railway environment,
- historical time series related to rare GNSS SIS fault events (satellite malfunctions and atmosphere anomalous behaviors)
- simulated faults for the new-coming constellations

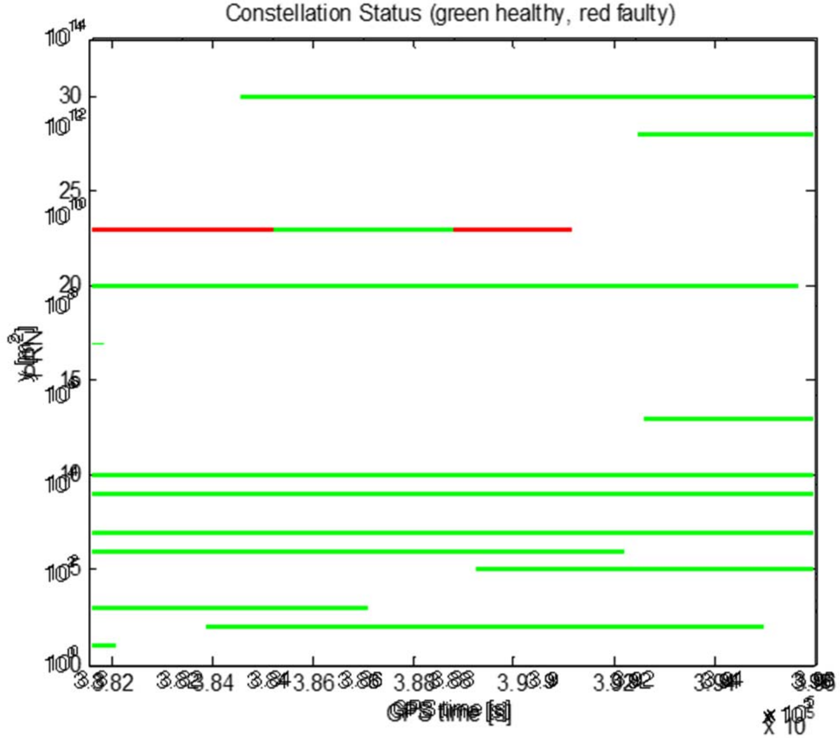


Integrity Check – Simulation Results

One faulty RIM with simulated fault corresponding to an increase of the measurement noise,



One faulty satellite (clock fault)



CONCLUSIONS

- Multi-constellation architectures offer higher degree of flexibility to reach the SIL-4 level (recommended for high demanding accuracy in the railways applications).
- Nevertheless, the availability of an augmentation network is of paramount importance in reducing the Protection Level.
- Sharing as much as possible of the supporting (i.e., augmentation) infrastructure and on board processing, including new developments such as Advanced Receiver Autonomous Integrity Monitoring (ARAIM), with the avionics field and automotive applications is a key factor for cost effectiveness.
- Definition of a standard for the Railway High Integrity Navigation Overlay System is a key success factor for spreading the GNSS application into the rail.
- Definition of a strategic roadmap for the adoption of an international standard is of primary concern.

Thanks for your attention

Ansaldo STS A Hitachi Group Company

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ROADMAP

1. Revision of **requirements** and **functionalities** expected worldwide in the short, medium and long term,
2. Investigation of **candidate solutions** (augmentation and integrity monitoring infrastructures, and On Board Units)
3. **Cost and Benefits trade-off** and selection of the reference architecture among the candidate solutions.
4. Realization of a **Trial Site**
5. Verification of the **reference architecture performance**
6. Dissemination and consensus sharing.

Track Area Augmentation Network SIS Monitoring

- The Track Area Augmentation Network Control Center (TAAN-CC) for each satellite, monitors
  - the Differential Pseudorange Residuals
  - the Double Difference Residuals

  of the pseudoranges observed by the reference stations, located in known position, see [1], [2].

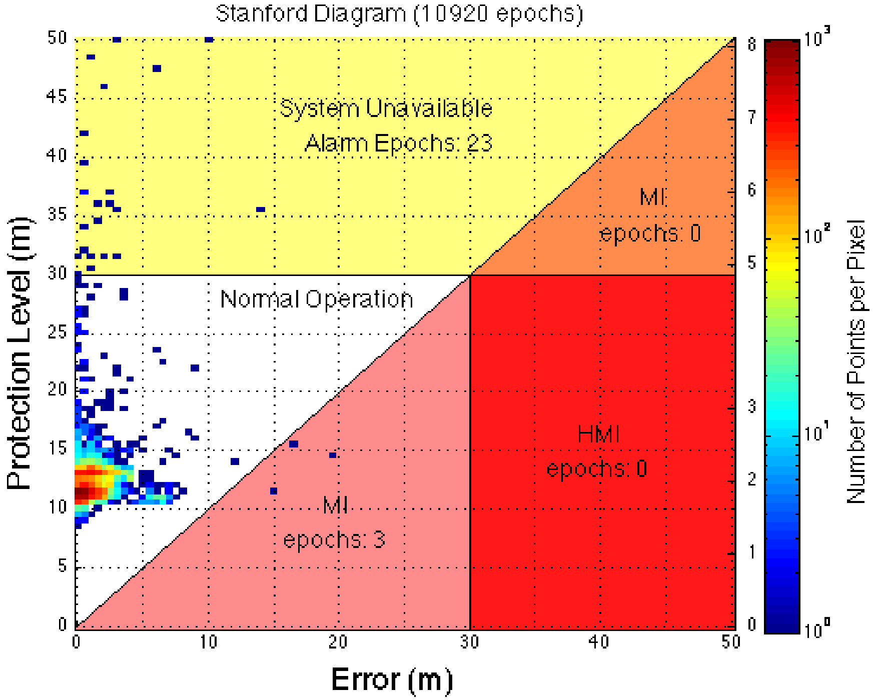
  - DPR monitoring allows detecting ephemeris error components parallel to the satellite line of sights,
  - DDR monitoring allows detecting those components orthogonal to the line of sights.

[1] S. Matsumoto, S. Pullen, M. Rotkowitz, and B. Pervan, “GPS Ephemeris Verification for Local Area Augmentation System (LAAS) Ground Stations”, in Proc. of ION GPS 2009,
[2] Neri, A., Capua, R., Salvatori, P., "High Integrity Two-tiers Augmentation Systems for Train Control Systems", ION Pacific PNT 2015, Honolulu, April 20-23 2015.

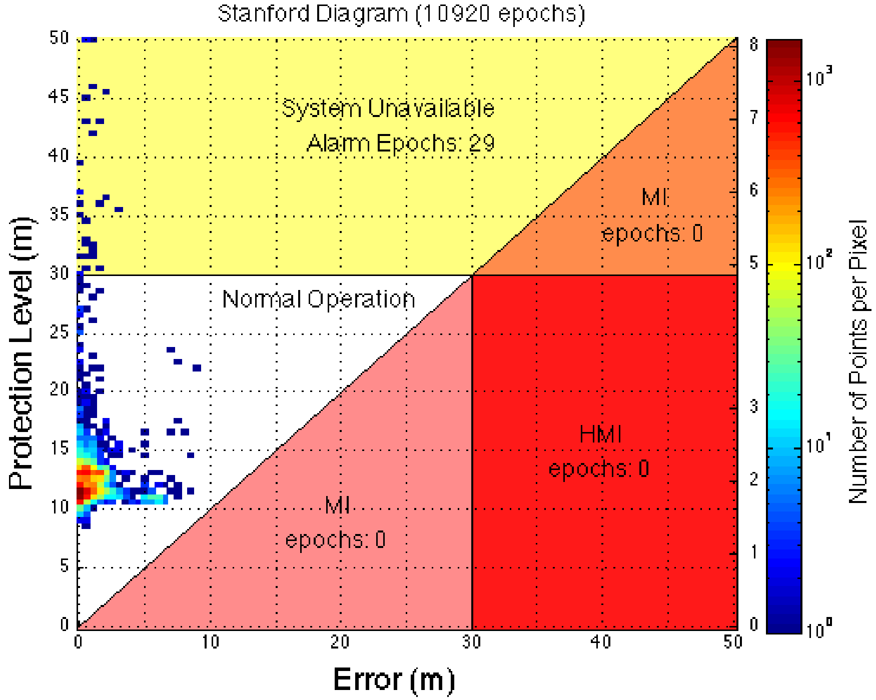
LDS Performance

RIM Fault mitigation effectiveness

Fault detection & exclusion OFF



Fault detection & exclusion ON



LDS Protection Levels

- Healthy Satellites (Nominal operations)

$$P_{MI/SH}^{LDS} \cong erfc\left(\frac{PL}{\sqrt{2}\sigma_{s/SH}}\right)$$

$$PL \cong \sqrt{2}\ erfc^{-1}\left(P_{MI/SH}^{LDS}\right)\sigma_{s/SH}$$

- One Faulty RIM, No Autonomous RAIM on Board

$$P_{MI/TAAN}^{LDS} \leq \underset{\mathbf{R}_{F_{RIM}}}{Max}\left\{erfc\left(\frac{PL}{\sqrt{2}\sigma_{\sigma^2_{s_{RP/F}}}(\mathbf{R}_{F_{RIM}})}\right)D_{G\chi^2_{N_z}}\left[\gamma_{z_n^i};\tilde{\mathbf{\Lambda}}_{z_n^i}(\mathbf{R}_{F_{RIM}})\right]\right\}$$

Integrity Check

For each RIM n of the 2nd tier:

a. Initialize the set $S_n^{H,SD}$ of healthy satellites to the set of visible satellites with elevation greater than the elevation mask.

b. Repeat

- for each satellite in $S_n^{H,SD}$ compute the quantity y_n^i

$$y_n^i = y_{cod,n}^i = \left[\zeta_n^i(k)\right]^T \zeta_n^i(k)$$

- Select the satellite with the largest y_n^i

$$\hat{i} = Arg\left\{\underset{i \in S_n^{H,SD}}{Max}\left[y_n^i\right]\right\}$$

- If $y_n^{\hat{i}}$ exceeds a predefined threshold $\gamma_{y_n^i}$
  - remove $\hat{i}$ from the healthy set $S_n^{H,SD}$
  - and mark the satellite as *unreliable*.

until $y_n^{\hat{i}} > \gamma_{y_n^i}$ and S_H is non empty.