ION GNSS+ 2017

ADVANCED GNSS ALGORITHMS FOR SAFE AUTONOMOUS VEHICLES

SEPTEMBER 29TH, 2017 — ION GNSS+ 2017, PORTLAND, OREGON, USA

SESSION A5: Autonomous and Assisted Vehicle Applications

INNOVATING SOLUTIONS

CONTENTS

- Motivation
- KIPL
- HYBRID GNSS/INS NAVIGATION + KIPL Results
- PPP + KIPL Results
- Conclusions

MOTIVATION

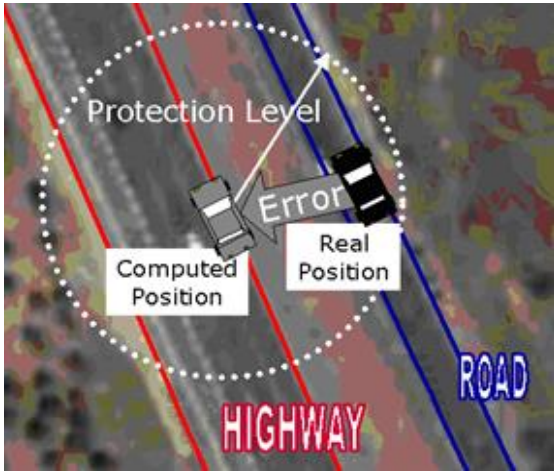
INNOVATING SOLUTIONS

INTEGRITY IN AUTONOMOUS DRIVING

- Autonomous Driving main concern → **Safety** of human beings
- Safety depends on a wide variety of factors
- Different sensors to measure dozens of parameters
- Accurate knowledge of these parameters is a key to safety, but even more important is to ensure their **reliability** ⇔ **integrity**
- The implementation of an integrity layer is crucial

Integrity is the key enabler

- In safety-critical applications it can be more important to know whether information is reliable than the precise information itself.



CHALLENGING SCENARIOS

- Dirty compared with aeronautical
  - multi-path, NLoS, interference…

- Especially in **urban** and **suburban** areas:
  - Reduced satellite visibility
  - Heavy multi-path (especially NLoS)
  - EGNOS and future GPS integrity concepts cannot be (directly) applied
  - RAIM not appropriate for these conditions

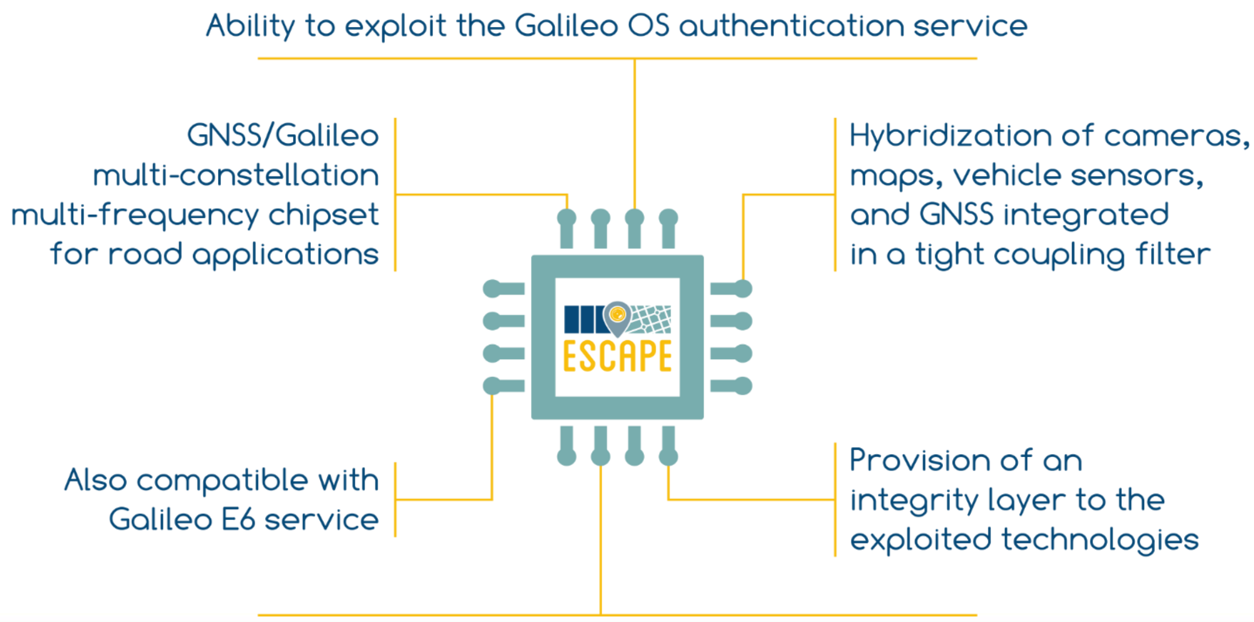
- GMV has been working for a decade in developing **GNSS-based navigation technologies for automotive applications** where integrity and accuracy are top-priority requirements

ESCAPE PROJECT

- Objective: present the performances achieved with GMV navigation technologies, which are an input to automotive applications → **ESCAPE** project

European Safety Critical Applications Positioning Engine (ESCAPE) is a project co-funded by the European GNSS Agency (GSA) under the European Union's Fundamental Elements research and development programme

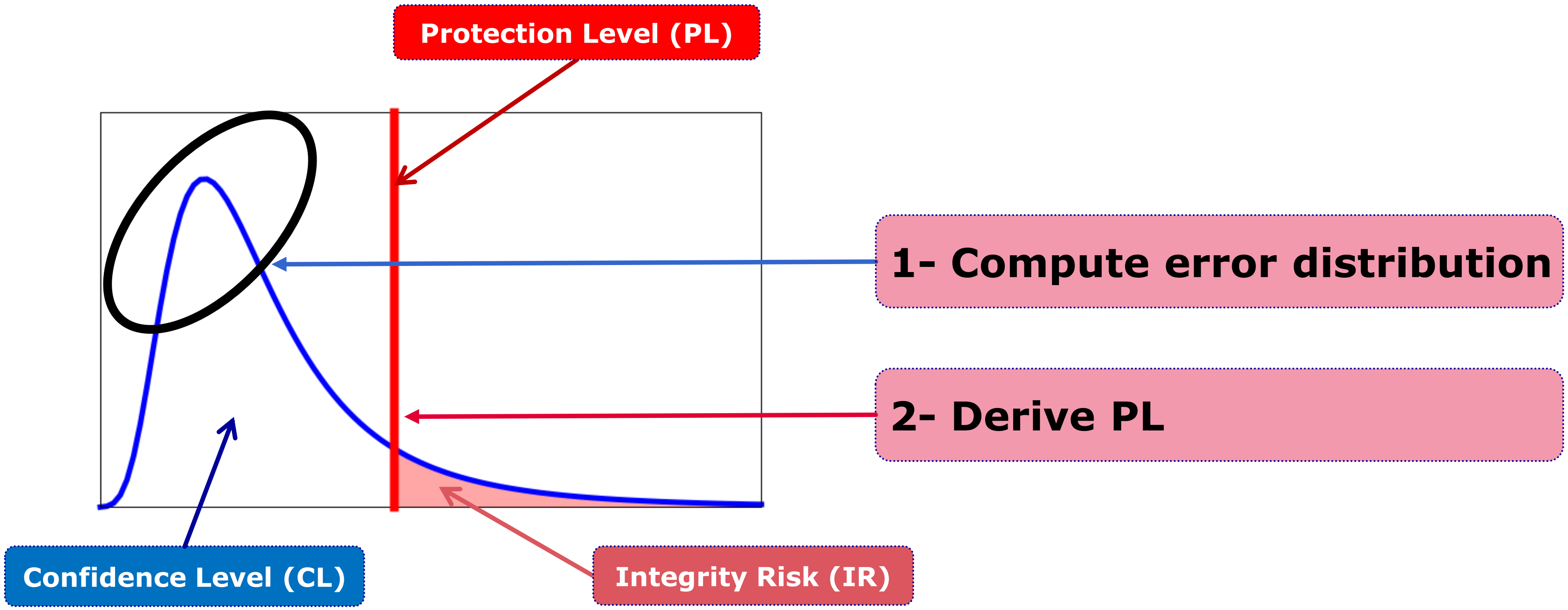
- ESCAPE main objective is to develop a <u>localisation system</u> to be employed in <u>safety critical applications</u> like Autonomous Driving (**AD**) or Advanced Driving Assistance Systems (**ADAS**)



KIPL INTEGRITY ALGORITHM

INNOVATING SOLUTIONS

INTEGRITY BOUND (PROTECTION LEVEL)



$$P(Error > PL) \le IR = 1 - CL$$

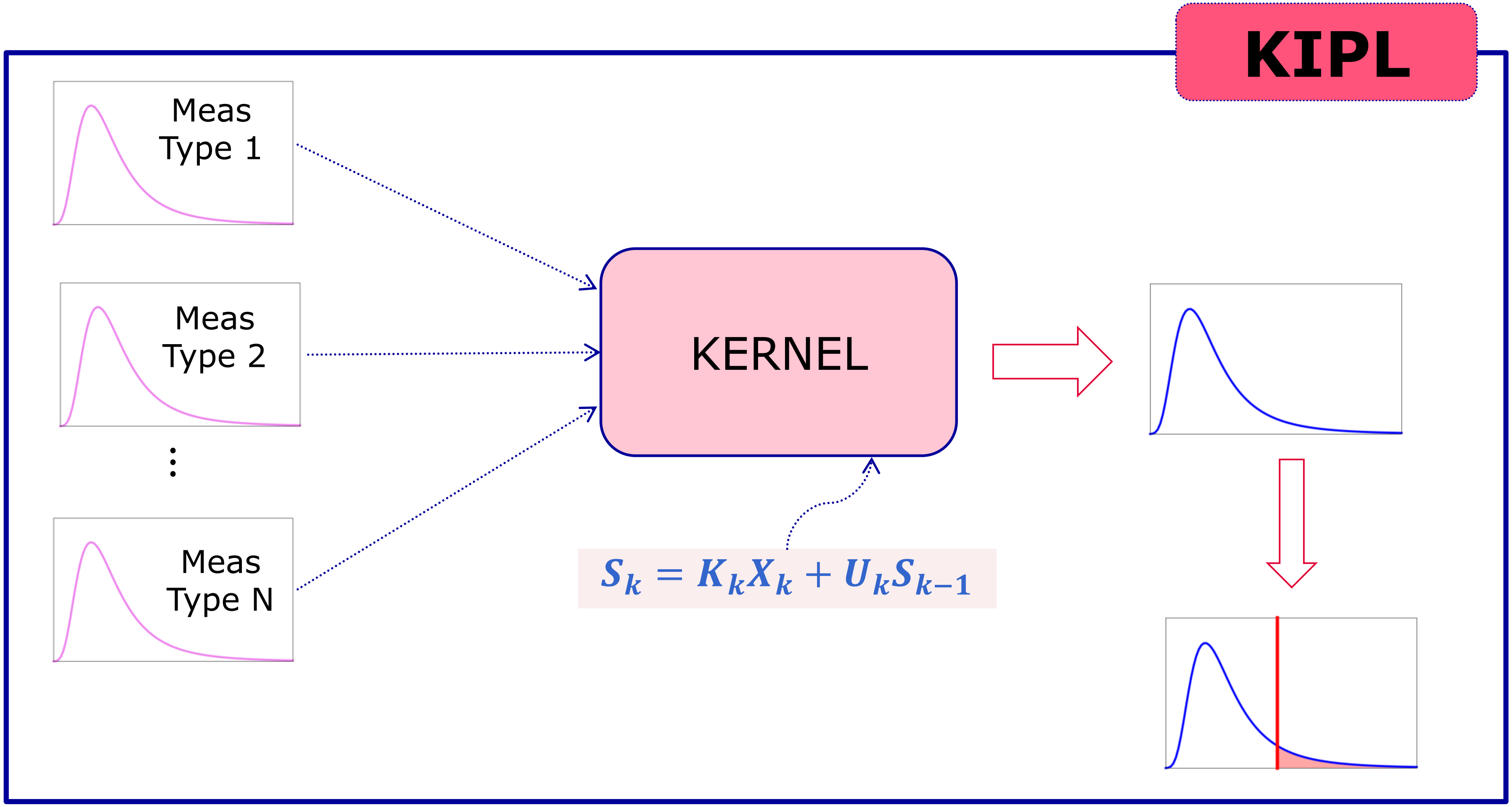
- Kalman Filters:
  - Real distribution not known ➔ use statistical model
  - Dependent on the conditions

KIPL INTEGRITY ALGORITHM

- **Driving principle** → new errors are introduced in the solution at each epoch, while the errors in the previous solution are also carried over to the new solution
- KIPL method introduces a probability distribution for each of the error sources: measurement errors, propagation errors, etc.
- Each distribution is processed and updated separately and provides a contribution to the total Protection Level, requiring:
  - **Characterization** of the measurements errors (dynamically monitored)
  - Update of the different errors distributions → requires a **detailed knowledge of the KF** update operations
- Once the distribution for the solution errors is known → obtain the protection level associated to any given Integrity Risk

KIPL INTEGRITY ALGORITHM

- KIPL method is a reliability bound computation algorithm that offers integrity to any Kalman navigation solution

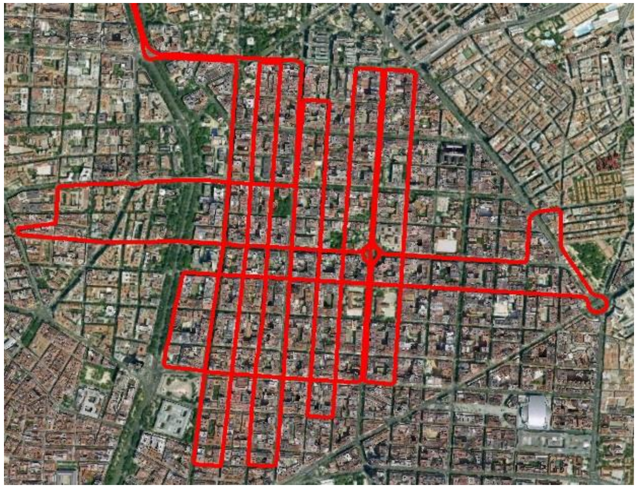


HYBRID GNSS/INS NAVIGATION + KIPL RESULTS

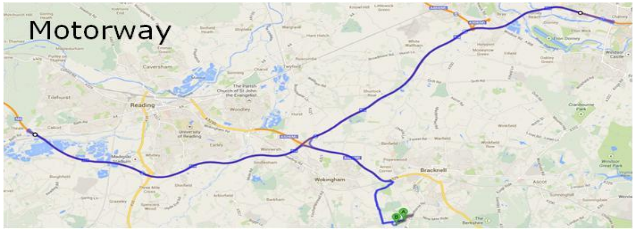
gmv® INNOVATING SOLUTIONS

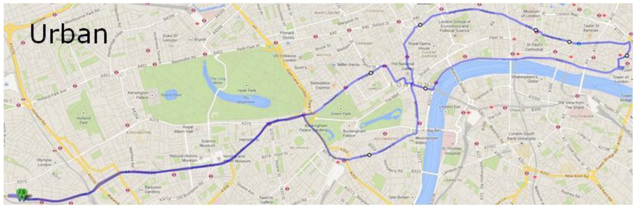
FIELD CAMPAIGNS

- MADRID
  - **Hybrid GNSS/INS Kalman Filter** + KIPL
    - using a low cost high sensitivity GPS&GLONASS receiver (STM Teseo-II)
  - Environments: Open-sky/Motorway, inter-urban and deep urban
  - More than 150,000 samples (42 h)
  - Reference track based on NovAtel SPAN with tactical grade IMU (iMAR FSAS)



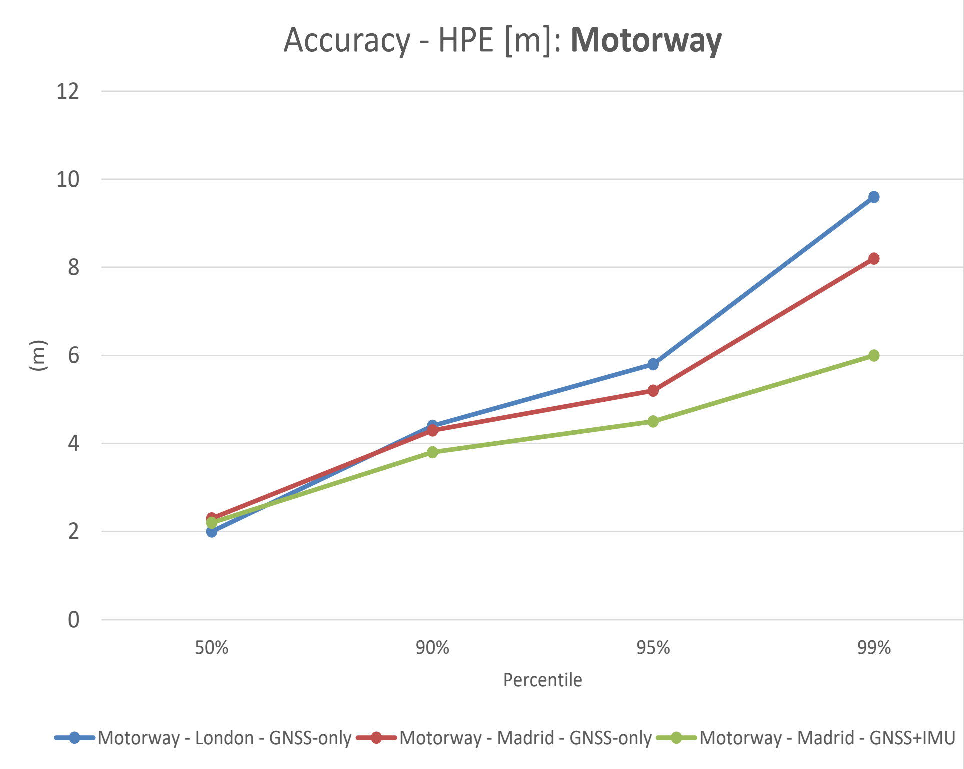
- LONDON
  - **GNSS Kalman Filter + KIPL** (without INS)
    - using GPS&GLONASS measurements generated with the SRX software receiver and the TRITON L1 FE
  - Environments: Motorway and deep urban
  - 400,000 samples (110 h)
  - Reference track based on NovAtel GPS&GLONASS L1/L2 with SPAN-CPT IMU and wheel sensor

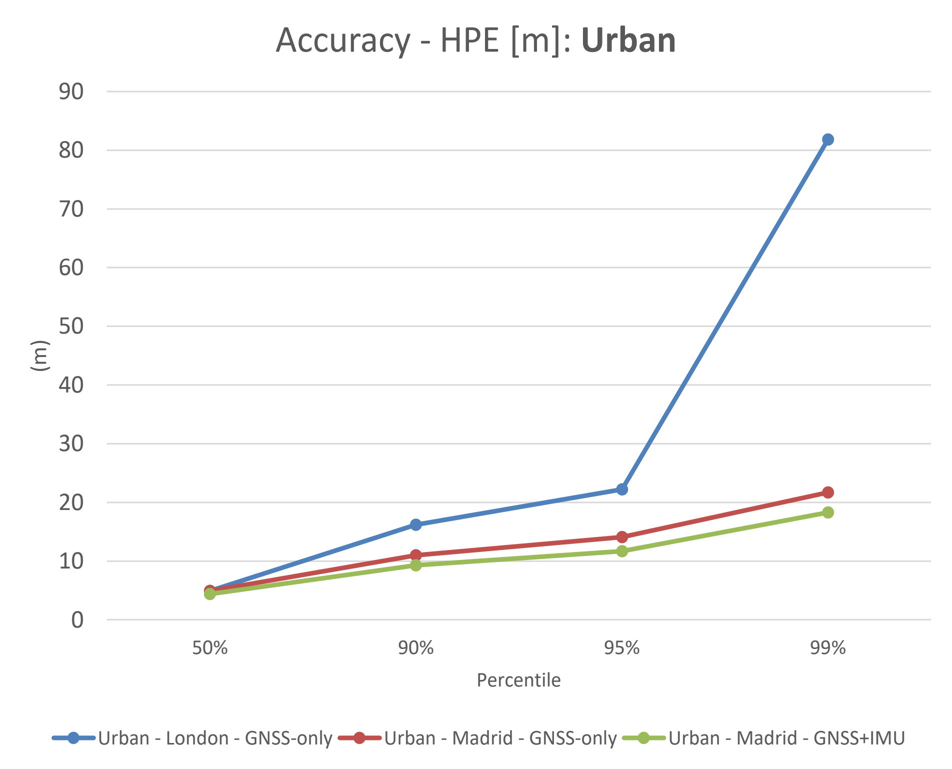




ACCURACY

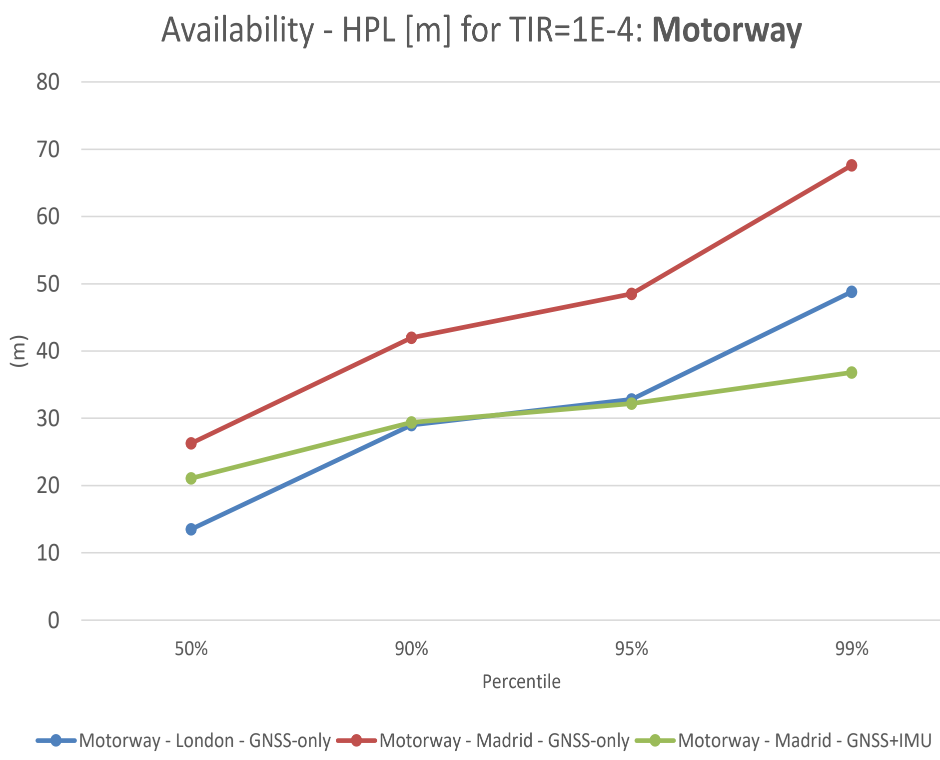
- <u>Accuracy</u>
  - Motorway/Open-sky: best accuracy, HPE is typically a few meters
  - Urban: HPE reaches 10-15 m around 10% of the epochs
  - The use of inertial sensors improves the performances in all the cases
  - The results are good for a low-cost receiver given the harshness of the environment

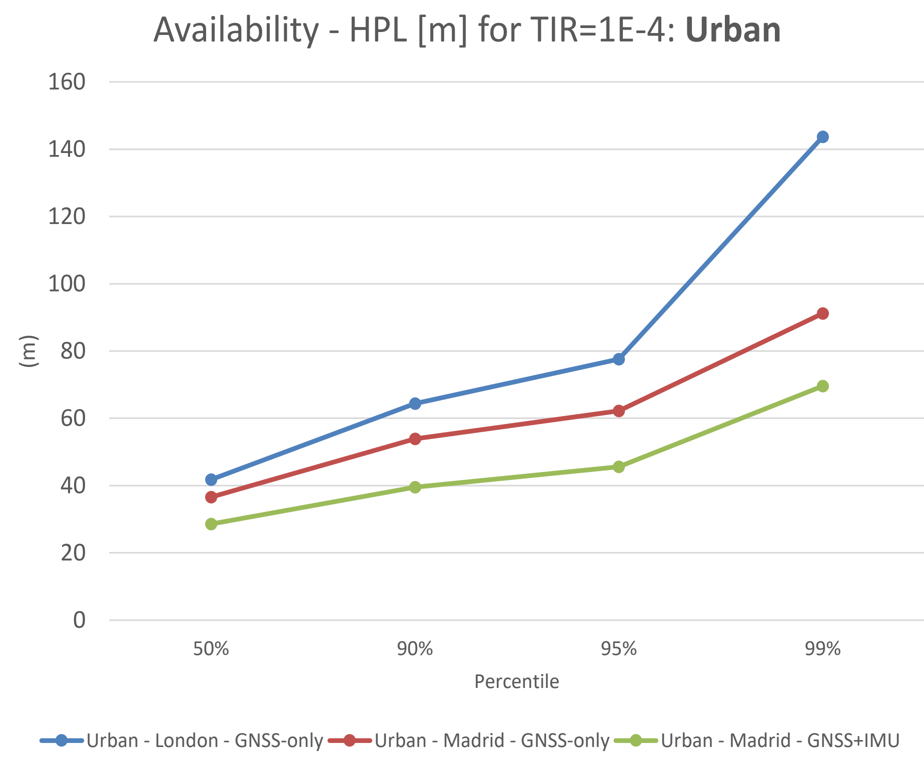




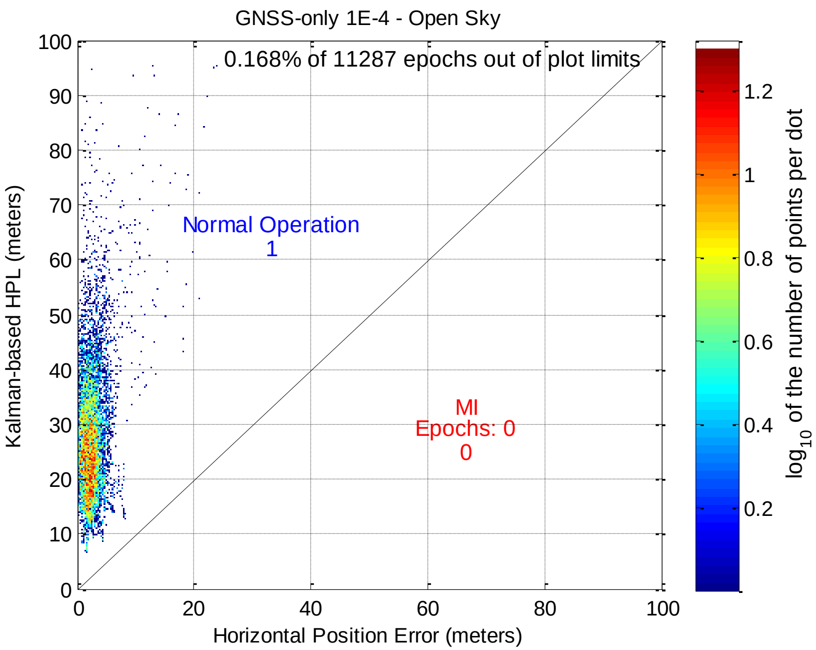
HORIZONTAL PROTECTION LEVELS (HPLs)

- <u>Integrity</u>
  - The obtained integrity failure rate values are **always below** the Target Integrity Risk (TIR)
- <u>Availability</u> (Size of the HPLs) for TIR=1E-4
  - Size of HPLs clearly improved by the use of **IMU data**

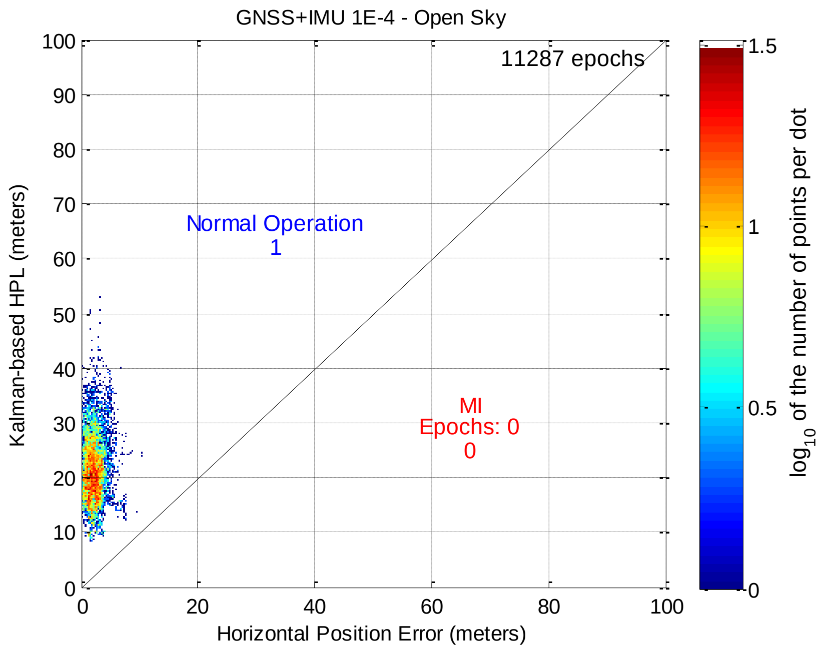




STANDFORD DIAGRAMS: OPEN-SKY/MOTORWAY

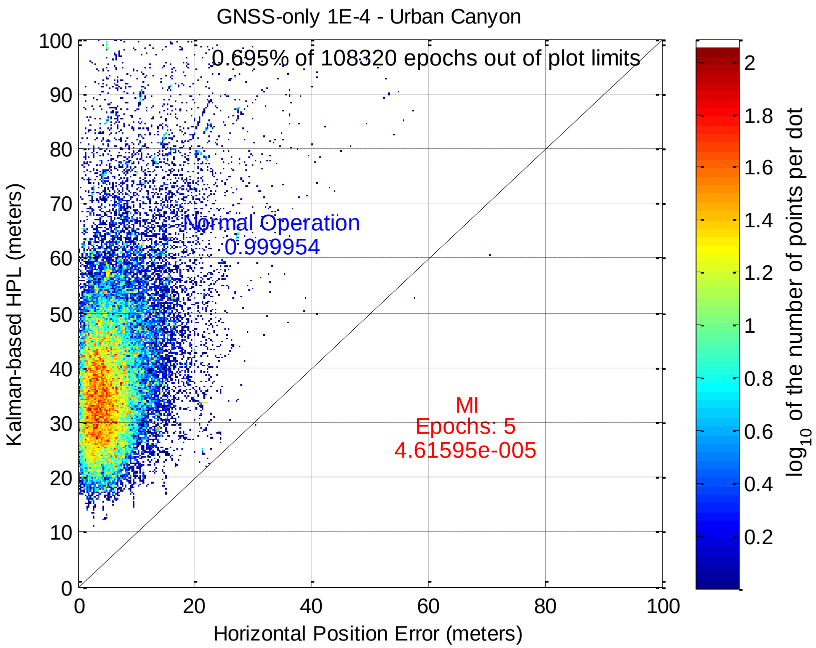


Madrid - GNSS-only

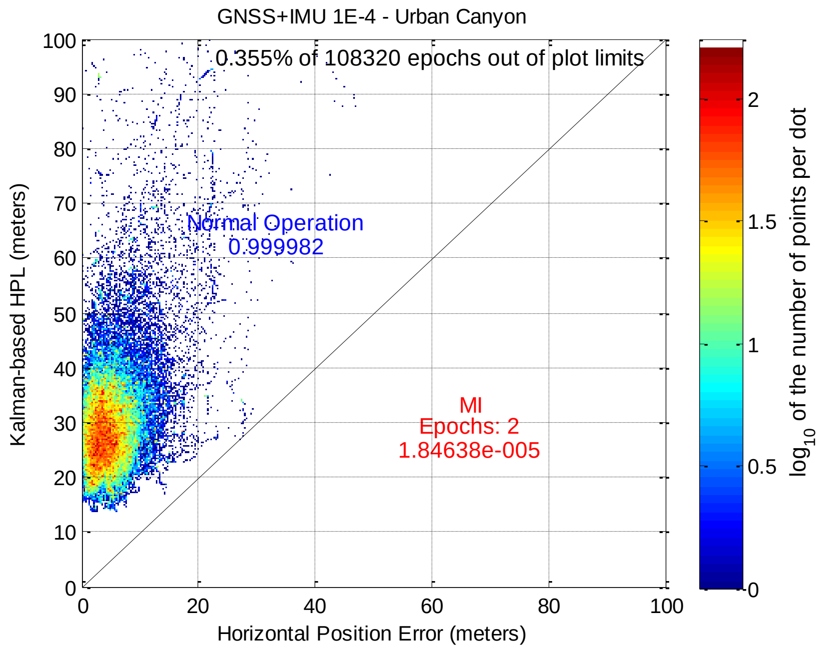


Madrid - GNSS+IMU

STANDFORD DIAGRAMS: DEEP URBAN



Madrid - GNSS-only

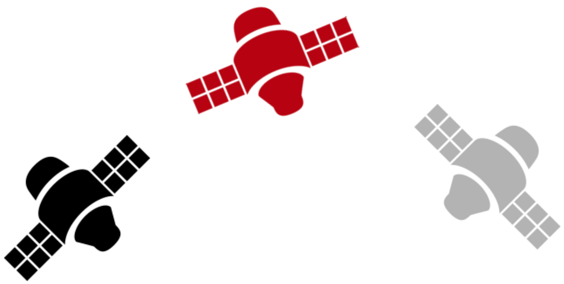


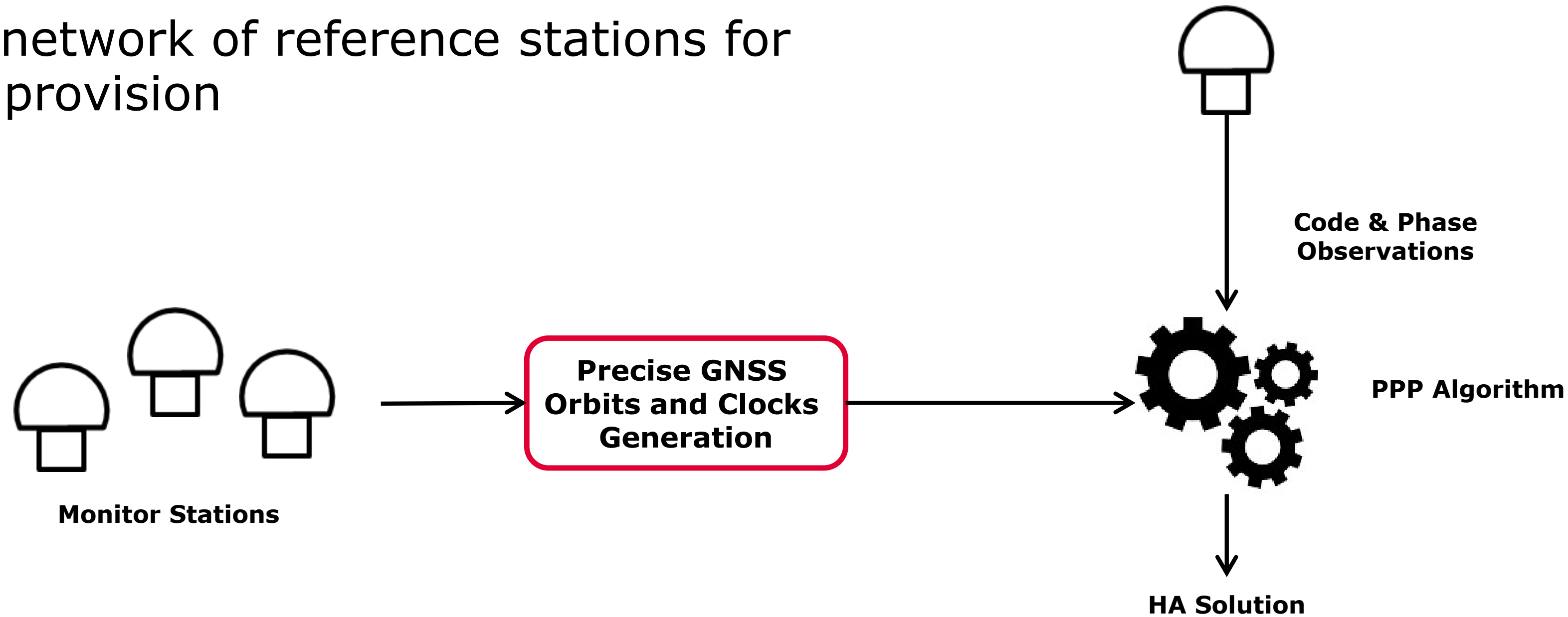
Madrid - GNSS+IMU

PPP + KIPL RESULTS

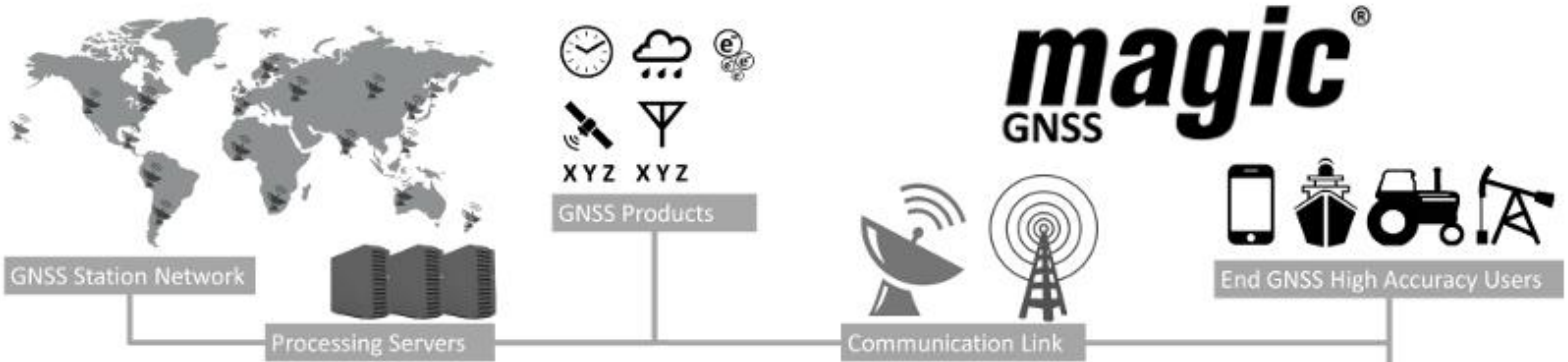
PRECISE POINT POSITIONING TECHNIQUE

- Two HA Position solutions: PPP and RTK
- PPP is an absolute positioning technique
- Worldwide or Regional coverage
- Relies on the use of precise orbits & clocks + observations + detailed models
- Sparse network of reference stations for service provision

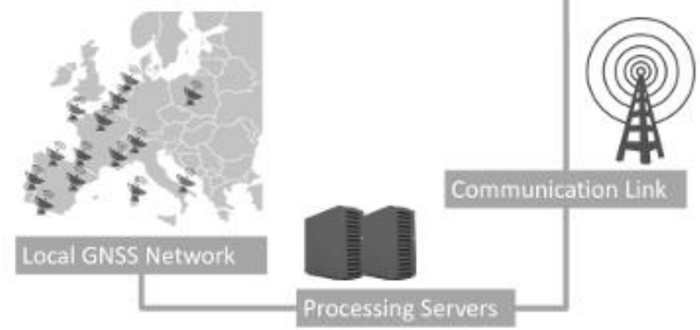




magicGNSS



- ***magicPPP*** provides the necessary end-to-end services and tools for PPP processing including:
  - Multi-constellation products provision
  - End-user applications for mobile devices and workstations
  - Compatible with DF and SF recievers
  - Multi-Frequency processing New
  - PPP + IMU New



NEW *magicPPP* FEATURES

Multi-Frequency Processing

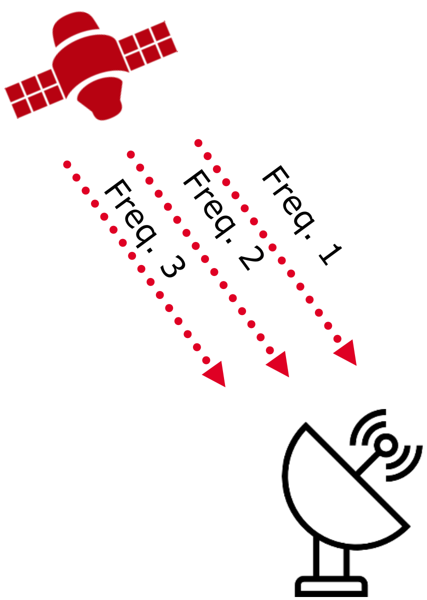
New

Individual Freqs.

\+

IF Combinations

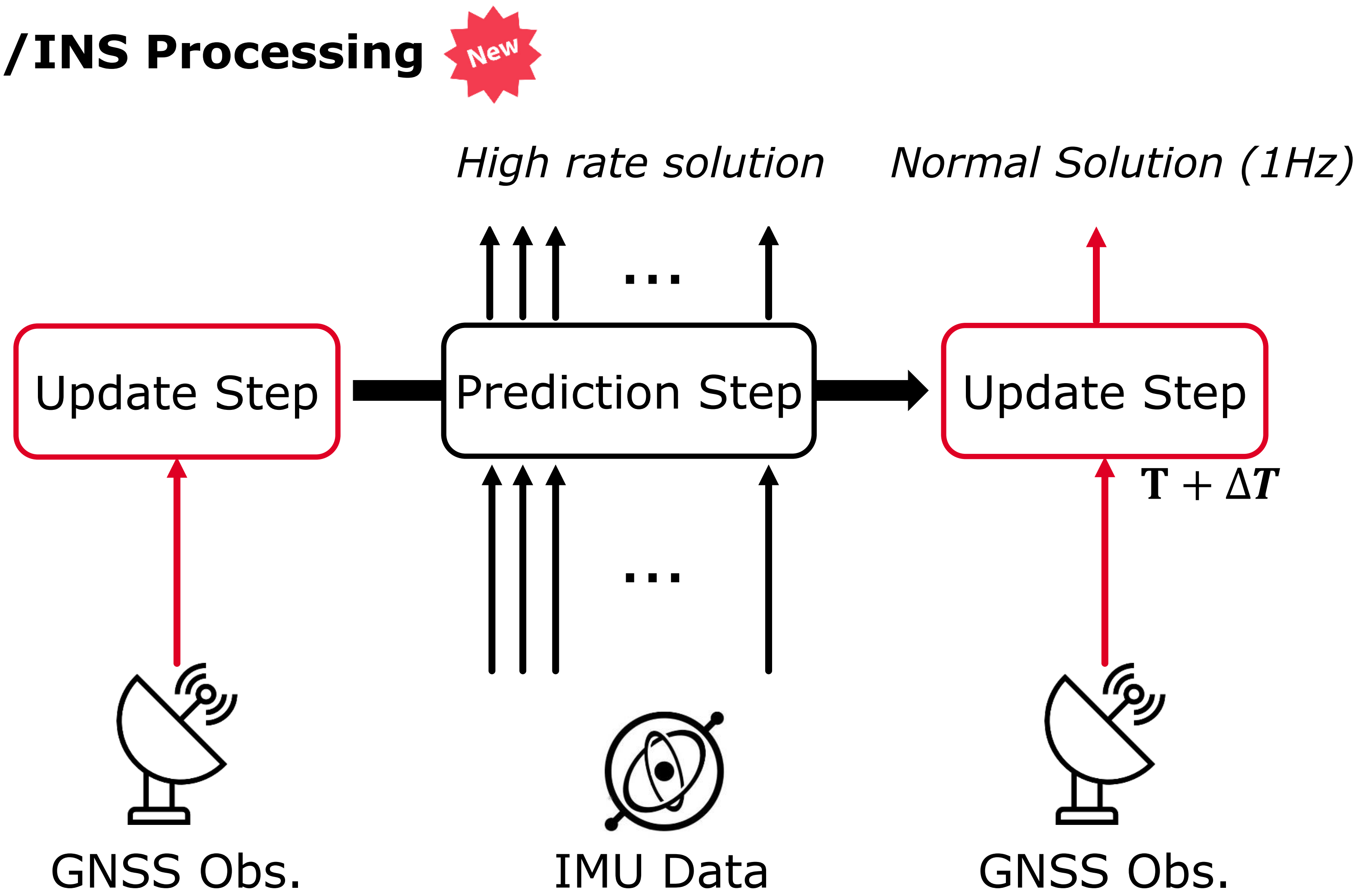
→ More data available → Better parameters estimation



→ ***magicPPP***
(SF + IF)

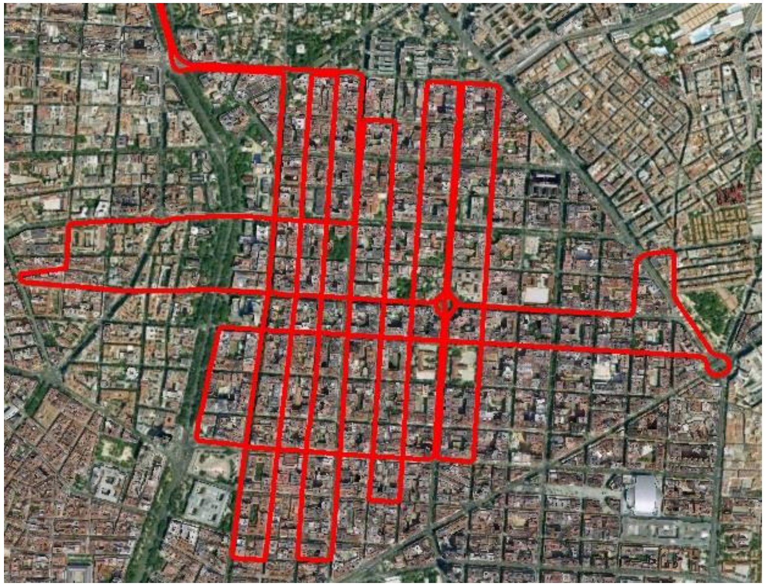
NEW *magicPPP* FEATURES

GNSS/INS Processing



PPP + IMU RESULTS

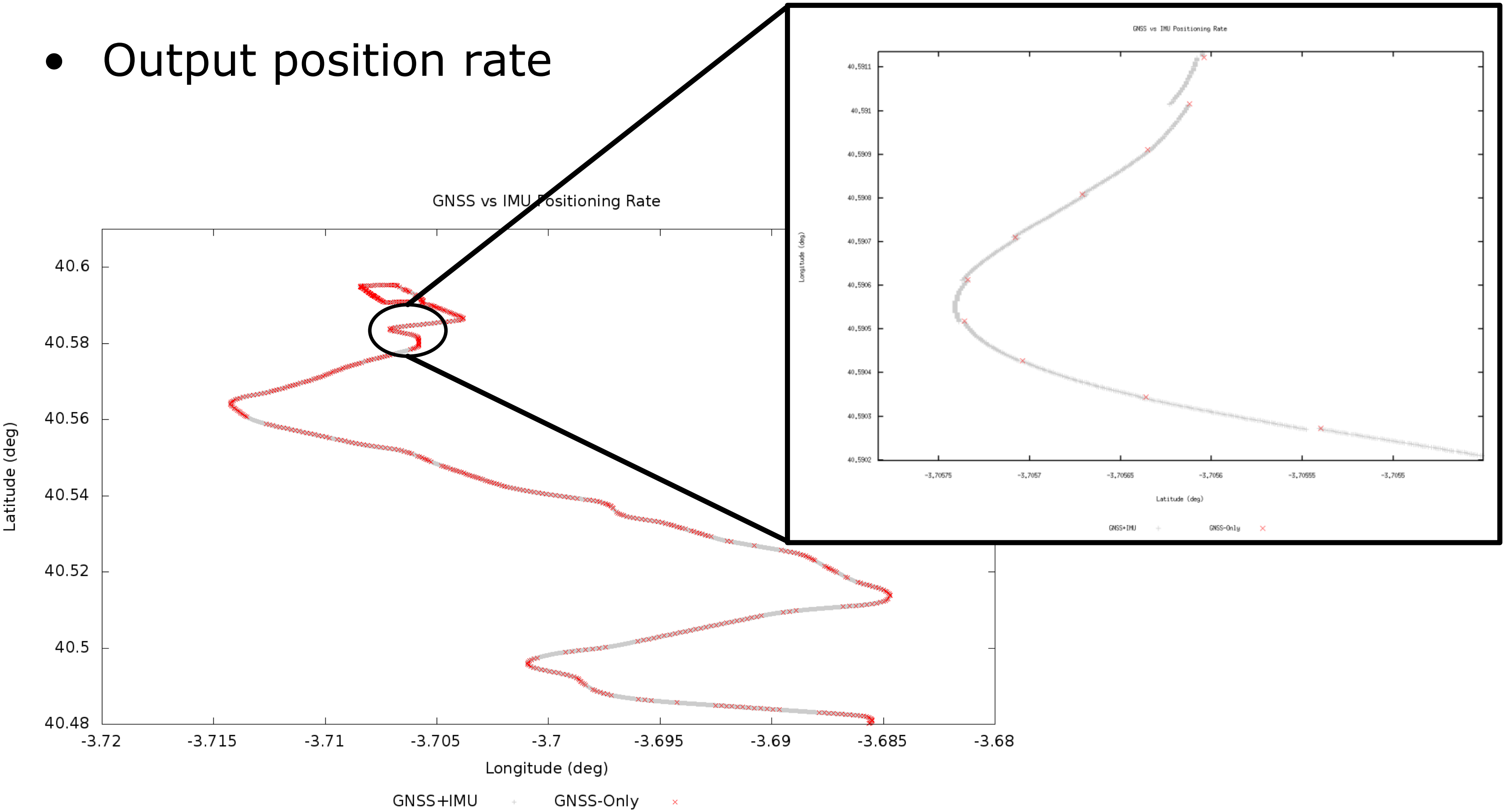
- Deep urban scenario located in **Madrid**
- **Better accuracy** is obtained when using IMU measurements



	RMS Horizontal Error (m)	RMS Vertical Error (m)
GNSS-Only	3.4	5.8
GNSS+IMU	2.9	4.1
Improvement	~14%	~30%

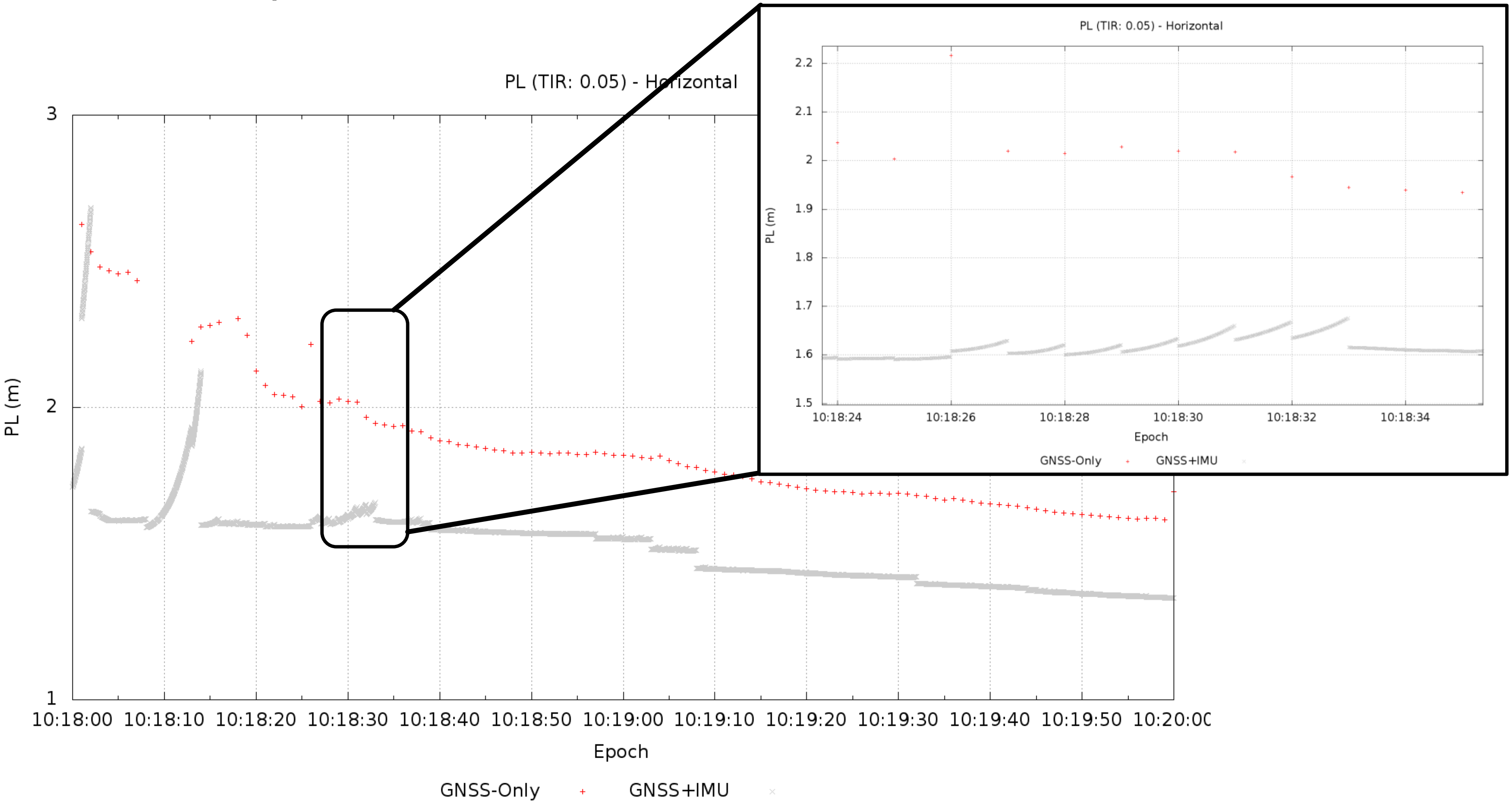
PPP + IMU RESULTS

- Output position rate



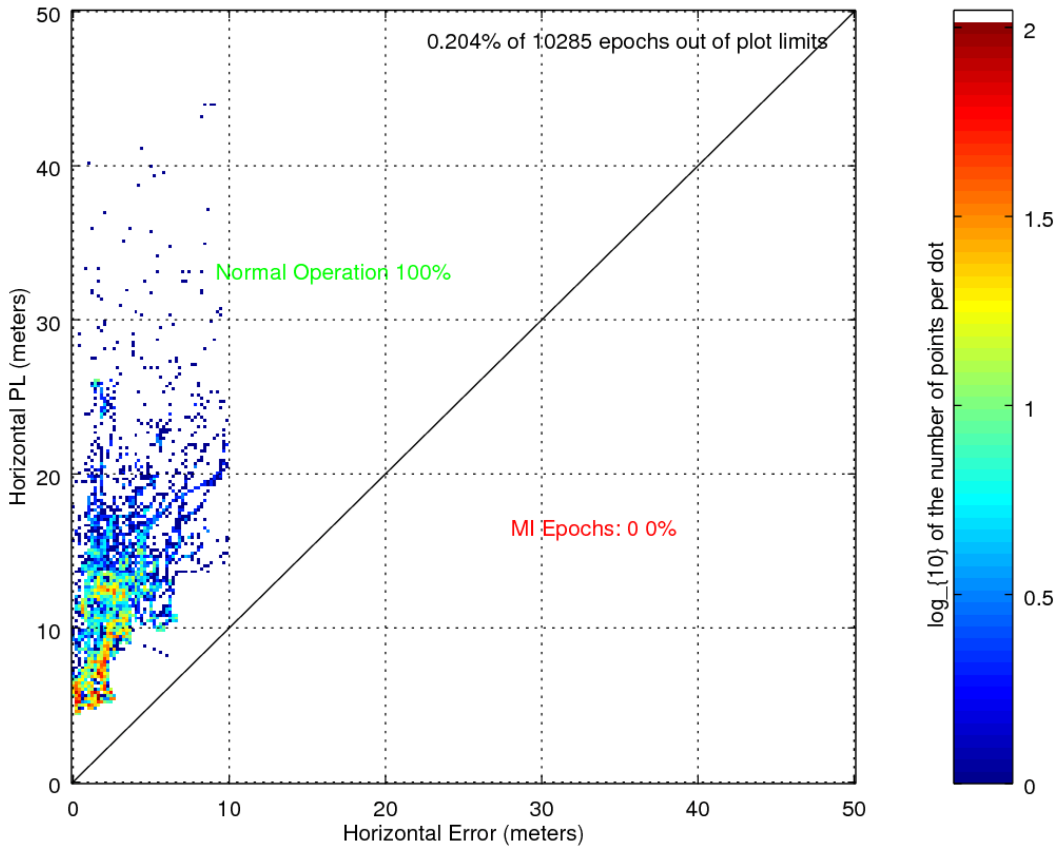
PPP + IMU RESULTS

- KIPL output rate → Horizontal PL for TIR=0.05



PPP + IMU RESULTS

- Stanford Diagram. Horizontal PL for TIR=1E-07



CONCLUSIONS

INNOVATING SOLUTIONS

CONCLUSIONS

- **Extensive field campaign** (from motorway to urban)
- **High level of accuracy** achieved by GMV navigation algorithms with low cost receivers
  - [Motorway] Hybrid GNSS/INS: <5m 95%; PPP: < 30 cm 95%
  - [Urban] Hybrid GNSS/INS: <12m 95%; PPP: < 6 m 95%
- **Integrity**: very good results in all the environments
  - Integrity failures below required limits
  - Protection levels well adapted to real performances
- **Coupling** the GNSS measurements **with INS** improves the accuracy and considerable reduces the size of the PLs
- **KIPL** is a reliability bound computation algorithm that offers integrity to Kalman Filter based navigation systems
  - suitable for a wide range of applications requiring a reliable navigation solution (e.g. **Autonomous Driving**)

Thank you

Enrique Domínguez Tijero

Email: edominguez@gmv.com

www.gmv.com

Visit us at booth **508**

INNOVATING SOLUTIONS