European GNSS Agency

# *Android GNSS Raw Measurements and Galileo High Accuracy Service*

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*29 November 2018*

***RNN`s New GNSS Signals seminar – opportunities for new PNT applications and improved robustness***

GALILEO EGNOS
NAVIGATION SOLUTIONS
POWERED BY EUROPE

# Presentation Outline

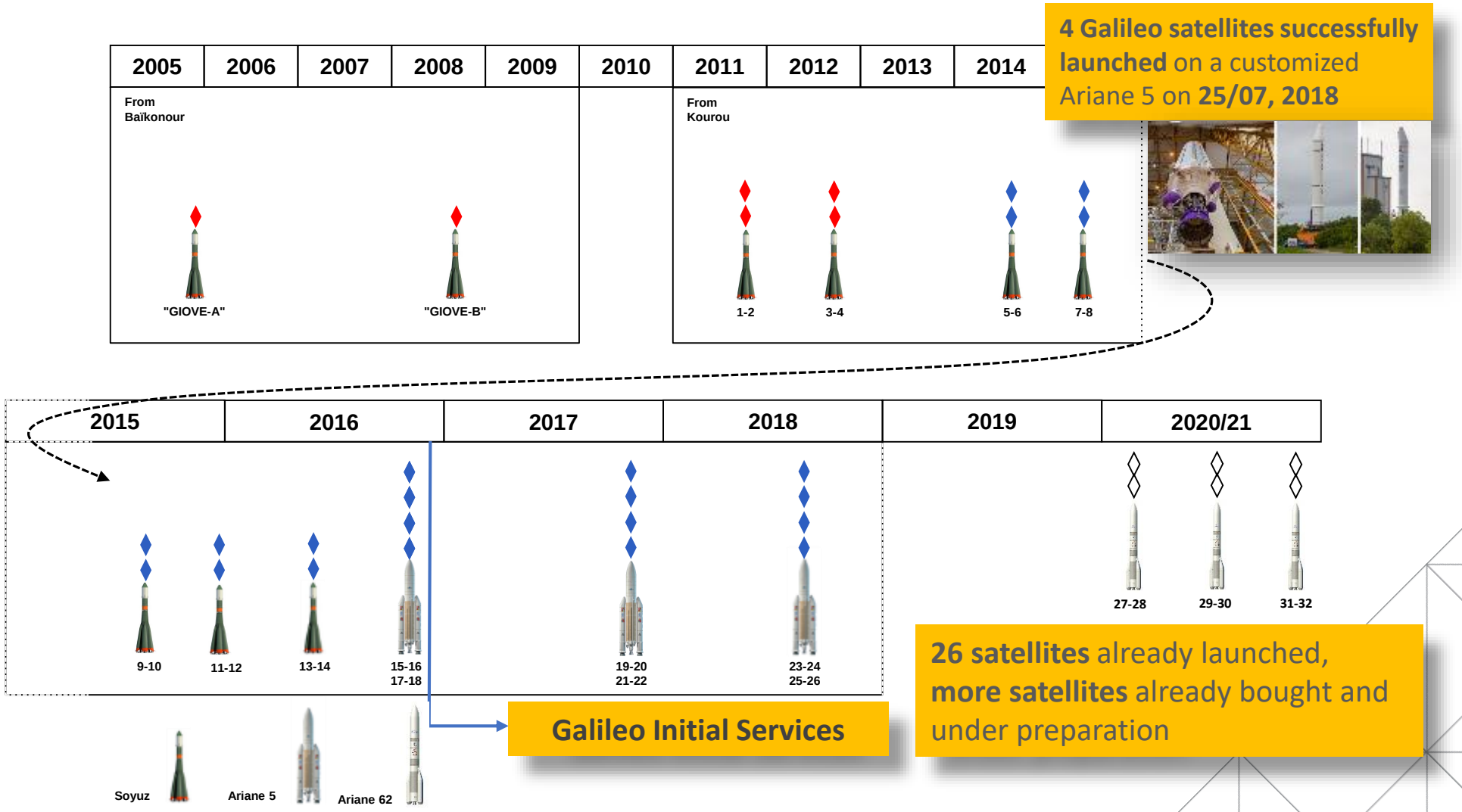
- GSA and Galileo HAS
- Android Raw Measurements
- Main benefits/uses of Raw measurements
- GSA Raw Measurements Task Force

# The European GNSS Agency (GSA) is responsible for market development and operations of Galileo and EGNOS

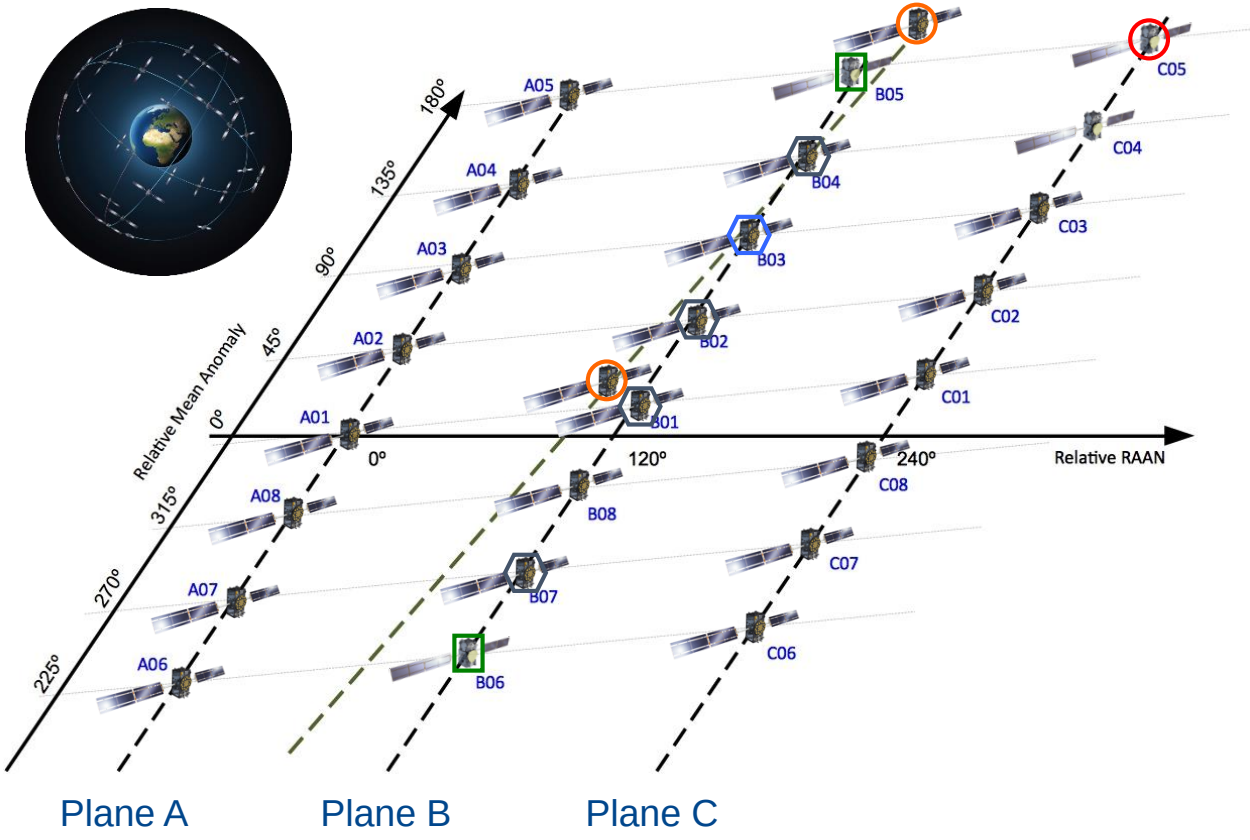

- Staff: around **160**
- Nationalities: **22**
- Headquarters: **Prague, Czech Republic**
- Other Locations:
  - France
  - The Netherlands
  - Spain
  - Belgium

- in charge of managing operations and service provision of Galileo (2017) and EGNOS (2014)
- delivering safe and secure European satellite system
- ensuring that European companies are using Galileo and EGNOS
- making sure that European citizens are benefitting from EGNOS and Galileo

# Galileo deployment is progressing



# Galileo Constellation Status




**Navigation Payload (18 Operational)**

- 26 satellites in orbit
- 4 under commissioning
- 2 in testing
- 1 spare
- 1 unavailable

**Search and Rescue Payload (19 Operational)**

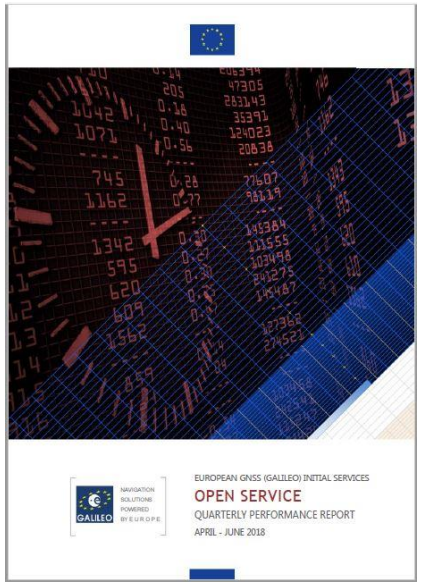
- 2 out of 26 satellites with no SAR Transponder (by design)
- 4 under commissioning
- 1 spare

0 unoccupied reference slots

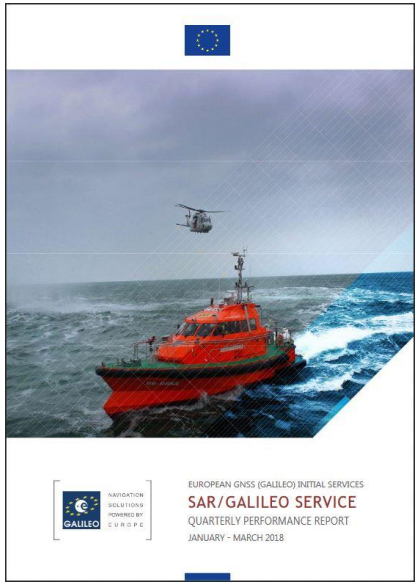
# Quarterly Performance Reports

Following the declaration of Initial Services in December 2016, the Galileo Initial Open Service (OS) and the Galileo Search and Rescue (SAR) Service Public Performance Reports are published quarterly, to provide the public with information about the Galileo OS and the Galileo SAR Service measured performance statistics

**OS Performance Report - Q2 2018**




**SAR Service Performance Report - Q2 2018**



# Galileo is the European GNSS offering a wide range of services

- **Freely accessible** service for **positioning, timing** and **navigation message authentication (OS-NMA)**
- **Encrypted service** designed for **greater robustness** and **higher availability**
- Assists **locating people in distress** and **confirms** that **help is on the way**
- **Freely accessible high accuracy** positioning service
- Authentication service based on the **E6 signal code encryption**, allowing for **increased robustness of professional applications**

**Open Service (OS)**

**OS-Navigation Message Authentication (OS-NMA)**

**Public Regulated Service (PRS)**

**Search and Rescue Service (SAR)**

**High Accuracy Service (HAS)**

**Signal Authentication Service (SAS)**

# Commercial Service goes for FREE

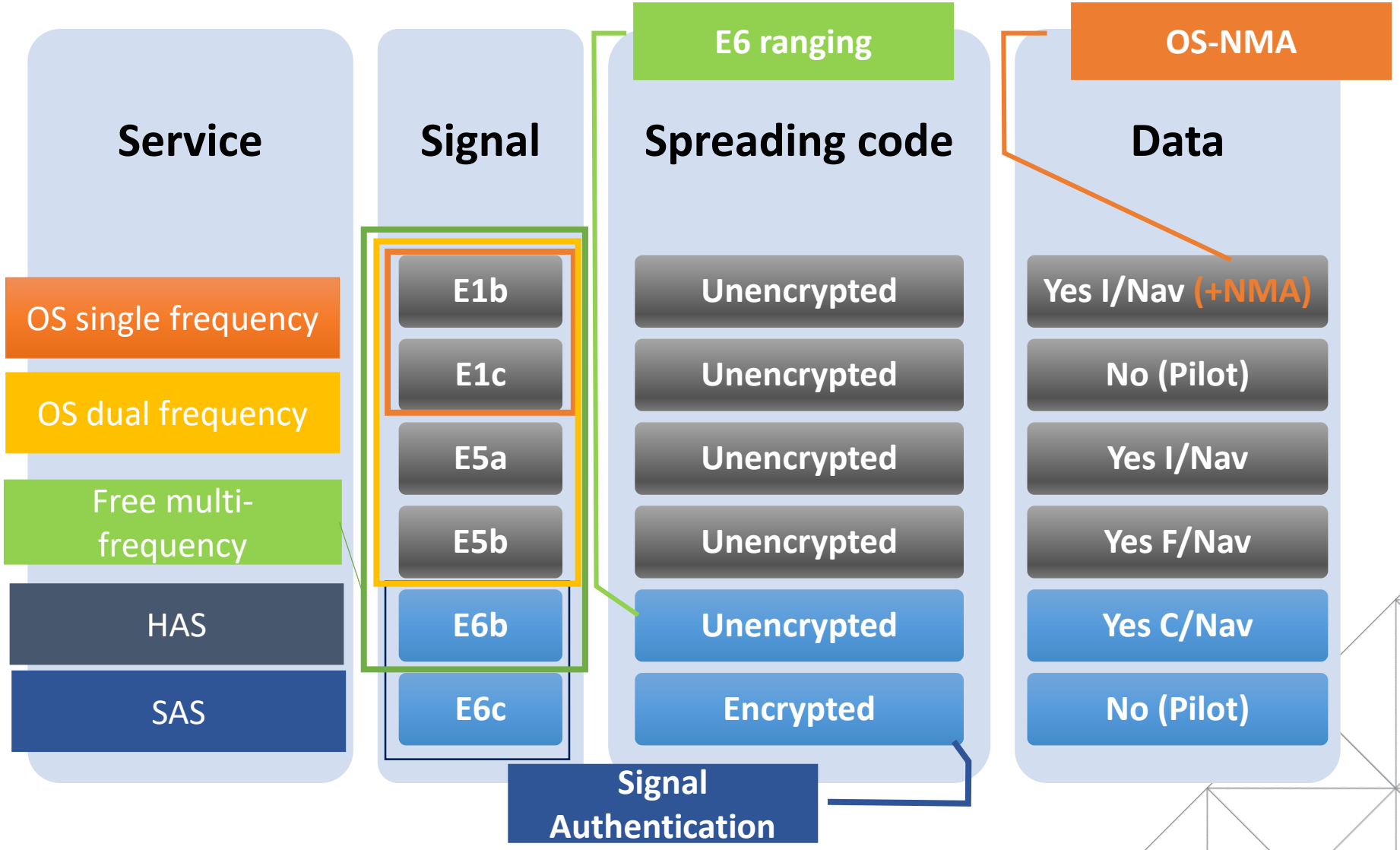
- As per EU GNSS regulation, **Galileo foresees a Commercial Service (CS) offered for a fee for professional apps**

- **In early 2017**, the EU adopted a **Decision** (Implementing Decision 2017/224) **defining the fee-based CS as High Accuracy Service (CS-HA) and Authentication**. CS-HA was foreseen to be based on commercial, proprietary format, not under Galileo's responsibility

- However, **new circumstances taken into account**: high accuracy broadening towards the mass market and being offered for free already by satnav providers and other public entities.

- Re-assessment process has culminated in an amendment to the Decision (Implementing Decision 2018/321), to redefine the High Accuracy service and **provide it for free.**

# Overview of signals
# Open service / High Accuracy Service / E6 ranging



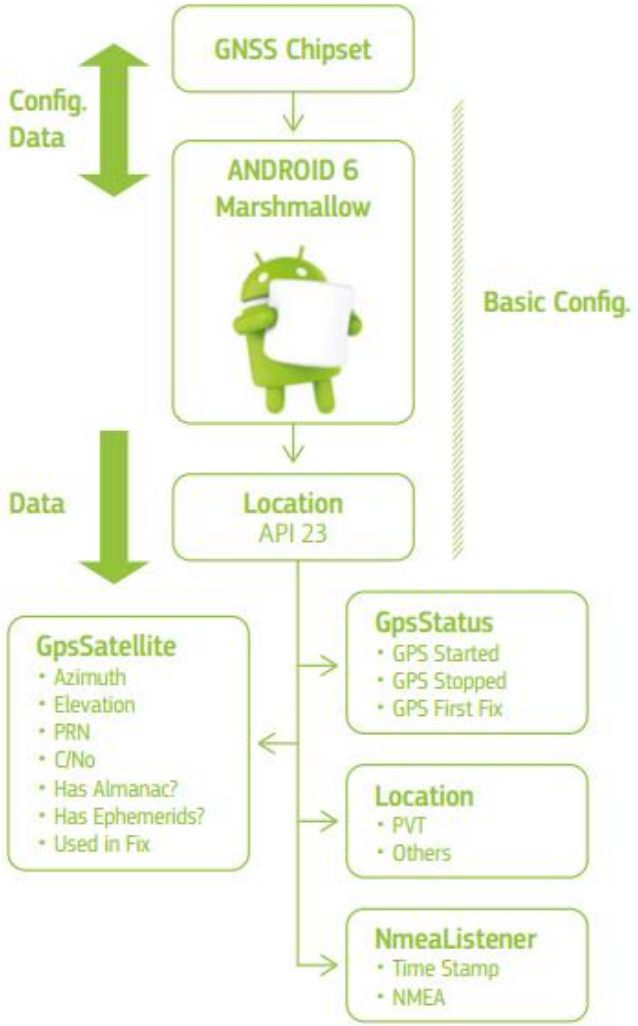
# HAS will be offered for free and using standard format

- High accuracy (PPP) corrections provided in the Galileo E6-B signal component (= no need for additional communication channel):
  - **Satellite orbits**
  - **Satellite clock corrections**
  - **Code biases for multi-frequency**
  - **Signal/correction quality information**
  - Phase biases (TBC)
  - Ionosphere in EU (to be confirmed)
- Corrections will be disseminated for (**E1, E5a, E5b, E6b, E5**(TBC)) and GPS (L1, L2, others TBC), and in the future potentially for other GNSS
- Global coverage when fully operational, partial coverage before (EU will be always included)
- HAS data transmitted **for free**, based on (used as a starting point) **open standard format RTCM CSSR** (currently under definition)
- ''target horizontal user **error around two decimetres**'', depending not only on user receiver, algorithm and environment (currently under definition)
- HAS distribution via terrestrial network (under consideration)

| | Signal and Data features |
|---|---|
| Frequency | 1278.75 MHz |
| Signal | E6B |
| Min. Power | -158 dBW |
| Modulation | BPSK(5) |
| Chip Rate | 5.115 Mcps |
| Code Length | 1 ms |
| Symbol Rate | 1000 sps |
| Data Rate | 492 bps |
| HA Data Rate | 448 bps (TBC) |
| Data Coding | FEC, as per Galileo OS SIS ICD, + interleaving 123 x 8 |
| Spreading Code Encryption | No |
| Data Format | TBD, but based on an open ICD. |
| Data (TBC) | Orbit and clock corrections, code and phase biases, SQM, flags, ionospheric information. |

# Android GNSS Raw Measurements (1)

- Google made available GNSS Android Raw Measurements in August 2016 with the release of Android 7 (Nougat)
- Before that, developers had access (with API 23) to the following Android classes
  - **GPS Satellite**, containing such basic satellite information as azimuth, elevation, PRN and C/No. It also flags if the satellite is used in the PVT solution and the availability of almanac and ephemerides.
  - **GPS Status** provides information about the status and solution of the GNSS chipset.
  - **Location**, indicating if a positional and time solution is provided.
  - **NMEA Listener**, providing basic NMEA sentences.



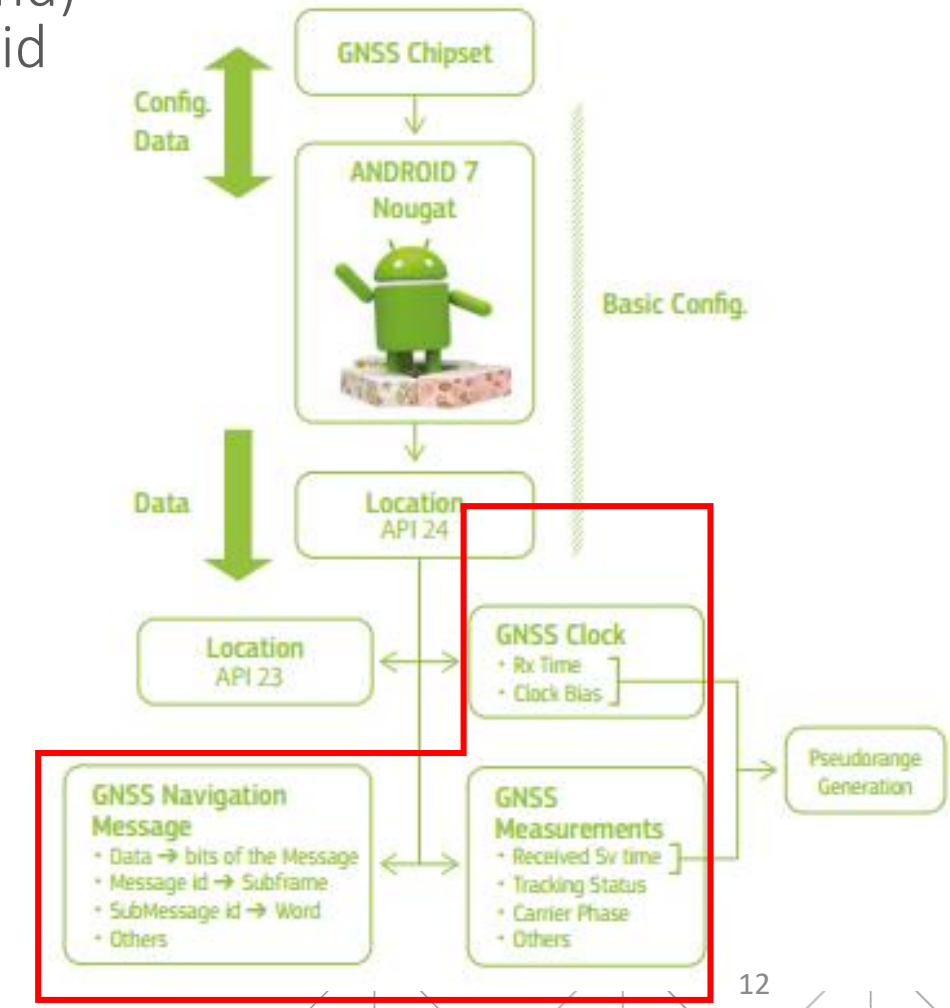
# Android GNSS Raw Measurements (2)

From API 24 (Android 7), developers have access to (API 23 and) the following GNSS raw and computed information via Android classes:

- *GNSS Clock*, that contains:
  - Receiver time;
  - Clock bias.

- *GNSS Navigation Message* that contains:
  - Navigation Message bits (all the constellations);
  - Navigation message status.

- *GNSS Measurement* that contains:
  - Received Satellite Time;
  - Code;
  - Carrier phase.

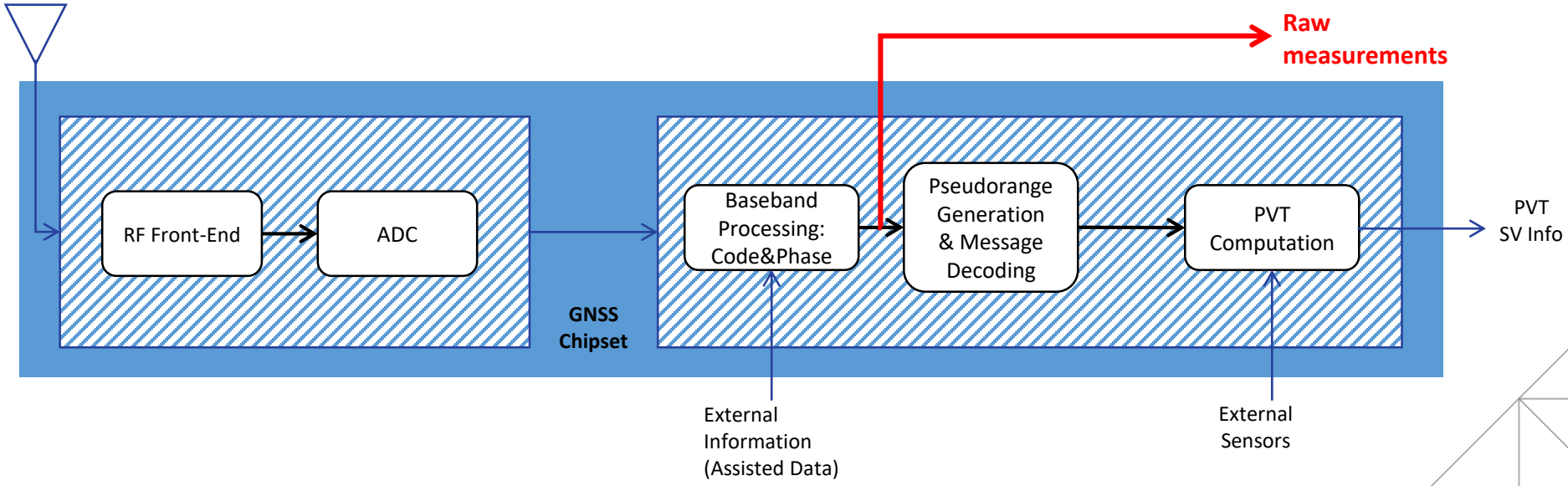


# Android GNSS Raw Measurements (3)

Processing chain in generic GNSS receiver

- RF signal is down converted to baseband or IF frequency
- The signal is digitalized by the ADC
- The baseband module acquires and tracks the code and the carrier
- Pseudoranges and PVT is computed

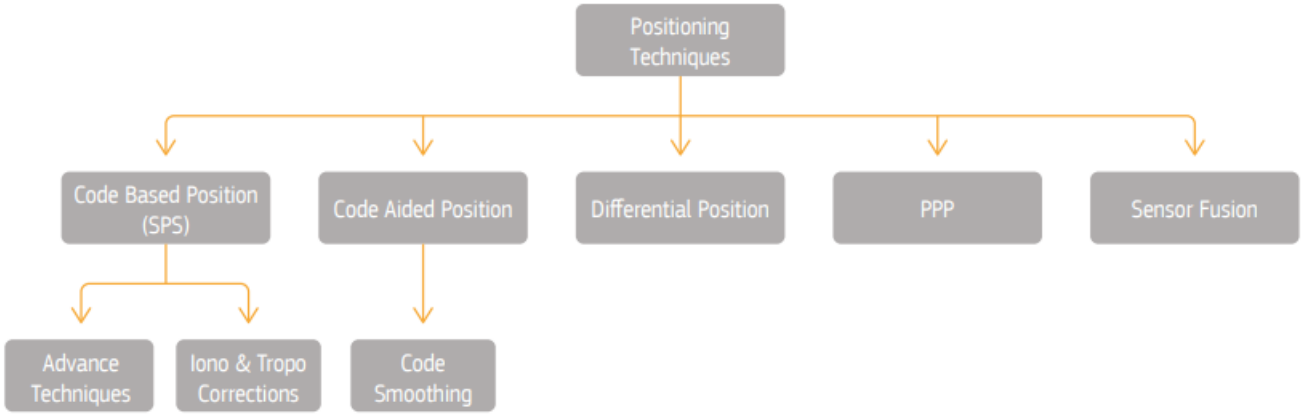
**<u>Raw measurements</u> comes before pseudorange generation !**

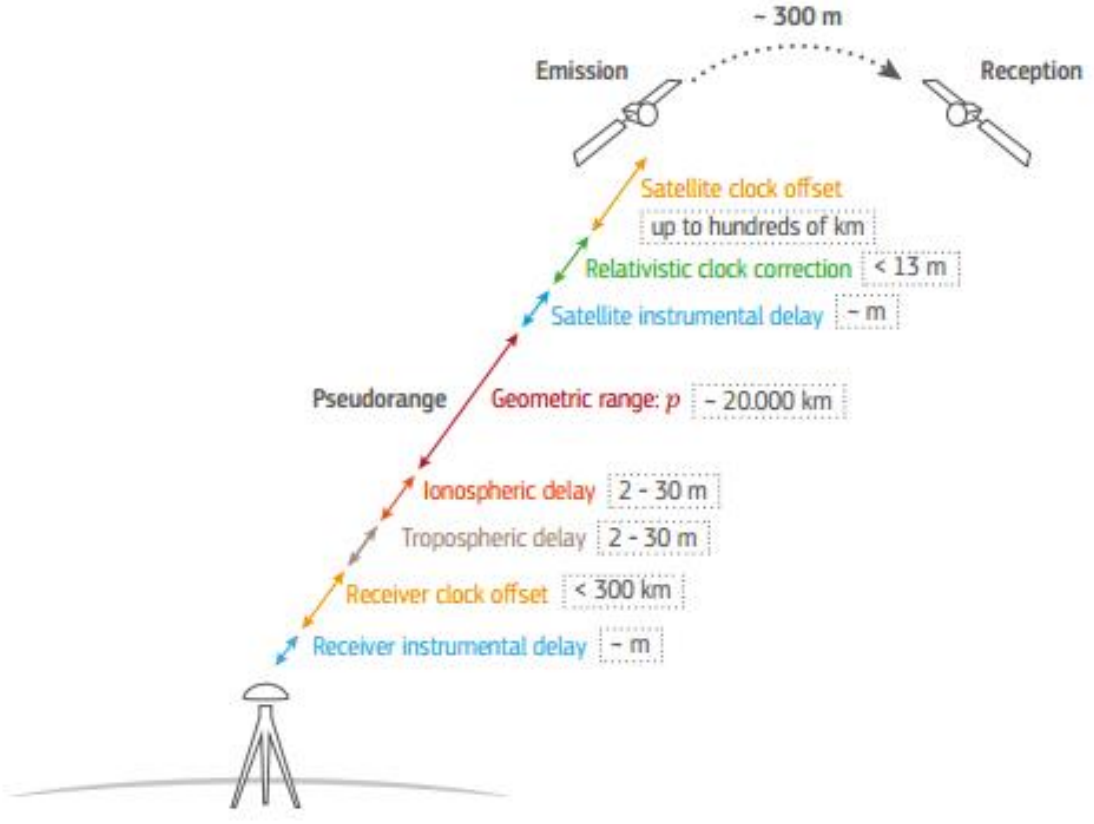


# Android GNSS Raw Measurements (4)

- Why is it so interesting?

→ you can use **android devices** to calculate pseudoranges, have access to carrier phase, and calculate PVT on your own, while using additional data from other sensors and sources



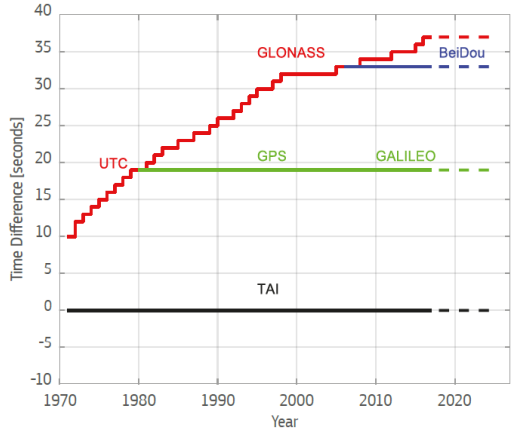

**Sources of GNSS pseudorange measurement errors**

# Challenges when generating the pseudoranges

- challenges when generating the pseudoranges
  - In Multi-constellation just one reference time must be used: GPS time usually chosen
  - The transmission time ($T_{Tx}$) can be ambiguous depending on your tracking status
  - Resolving the bias between hardware receiver time (internal timescale provided by the Rx) and GNSS time

$$\rho = (t_{Rx} - t_{Tx}) \cdot c$$

- for more see


| GPS | | GALILEO | | GLONASS | | BeiDou | |
|---|---|---|---|---|---|---|---|
| Sync | Status Time | Sync | Status Time | Sync | Status Time | Sync | Status Time |
| C/A code | 1 ms | E1BC code | 4 ms | C/A code | 1 ms | C/A code | 1 ms |
| Bit | 20 ms | E1C 2nd code | 100 ms | Bit | 20 ms | Bit | 20 ms |
| Subframe sync | 6 s | E1B page | 2 s | String | 2 s | Subframe sync | 6 s |
| TOW | 1 week | TOW | 1 week | Time of Day | 1 day | TOW | 1 week |

Values bigger than the propagation time can be used for unambiguous pseudorange determination

# Android devices that support raw measurements

| Model | Android version | Automatic Gain Control | Navigation messages | Accumulated delta range | HW clock | L5 Support | Global systems |
|---|---|---|---|---|---|---|---|
| Pixel 3 XL | 9.0 | yes | no | yes | yes | no | GPS GLONASS GALILEO BeiDou |
| Pixel 3 | 9.0 | yes | no | yes | yes | no | GPS GLONASS GALILEO BeiDou |
| Vivo X21 | 9.0 | no | no | no | yes | no | GPS GLONASS BeiDou |
| OPPO R15 Pro | 9.0 | no | no | no | yes | no | GPS GLONASS GALILEO |
| Xiaomi Mi 8 | 8.1 | no | yes | yes | | | |
| LG V40 ThinQ | 8.1 | no | no | no | | | QZSS |
| OnePlust 6T | 9.0 | no | no | no | yes | no | GPS GLONASS QZSS |
| Samsung Note 9 | 8.1 | no | no | no | yes | no | GPS GLONASS QZSS SBAS |
| LG G7 ThinQ | 8.0 | no | no | no | yes | no | GPS GLONASS |
| Xiaomi Mix 2S | 9.0 | no | no | no | yes | no | GPS GLONASS SBAS |
| Huawei P20 | 8.1 | no | yes | yes | yes | no | GPS GLONASS QZSS |
| Samsung Galaxy S9 (Exynos)[1] | 8.0 | no | yes | yes | yes | no | GPS GLONASS QZSS |
| Samsung Galaxy S9+ | 8.0 | no | no | no | yes | no | GPS GLONASS |
| Sony Xperia XZ2 | 8.0 | no | no | no | yes | no | GPS GLONASS QZSS |
| OPPO R15 | 9.0 | no | no | no | yes | no | GPS GLONASS GALILEO BeiDou |
| HTC U11 Plus | 8.0 | no | no | no | yes | no | GPS GLONASS |
| HTC U11 Life | 8.0 | no | no | no | yes | no | GPS GLONASS |
| Huawei Mate 10 | 8.0 | no | yes | yes | yes | no | GPS GLONASS |
| Google Pixel 2 | 8.0 | yes | no | no | yes | no | GPS GLONASS GALILEO BeiDou QZSS |
| Sony Xperia XZ1 | 8.0 | no | no | no | yes | no | GPS GLONASS GALILEO BeiDou |
| Samsung Note 8 (Exynos) | 7.1 | no | yes | yes | yes | no | GPS GLONASS GALILEO BeiDou |
| Samsung Note 8 (QCOM) | 7.1 | no | no | no | yes | no | GPS GLONASS GALILEO BeiDou |
| LG V30 | 7.1.2 | no | no | no | yes | no | GPS GLONASS |
| Moto X4 2017 | 7.1 | no | no | no | yes | no | GPS GLONASS |
| Essential PH-1 | 7.1 | no | no | no | yes | no | GPS GLONASS |
| Moto Z2 | 7.1 | no | no | no | yes | no | GPS GLONASS |
| HTC U11 | 7.1 | no | no | no | yes | no | GPS GLONASS |
| OPPO R11 | 7.1 | no | no | no | yes | no | GPS GLONASS GALILEO BeiDou |
| Huawei Honor 9 | 7.0 | no | yes | yes | yes | no | GPS GLONASS |
| Samsung S8 (Exynos)[2] | 7.0 | no | yes | yes | yes | no | GPS GLONASS GALILEO BeiDou QZSS |
| | | | | | no | yes | no GPS |
| | | | | | yes | yes | no GPS GLONASS GALILEO BeiDou QZSS |
| Huawei P10 Lite | 7.0 | no | no | no | yes | no | GPS |
| Huawei Honor 8 | 7.0 | no | yes | yes | yes | no | GPS GLONASS BeiDou |
| Huawei Mate 9 | 7.0 | no | yes | yes | yes | no | GPS GLONASS BeiDou |
| Huawei P9 | 7.0 | no | yes | yes | yes | no | GPS GLONASS BeiDou |
| Google Pixel XL | 7.0 | no | no | no | yes | no | GPS |
| Google Pixel | 7.0 | no | no | no | yes | no | GPS |
| Nexus 6P[4] | 7.0 | no | no | no | no | no | GPS |
| Nexus 5X[4] | 7.0 | no | no | no | no | no | GPS |
| Nexus 9 (non cellular version)[5] | 7.1 | no | yes | yes | yes | no | GPS GLONASS |

Go to https://developer.android.com/guide/topics/sensors/gnss

# What are the benefits/ main uses of GNSS raw measurements?

**Four main areas of use are enabled by GNSS raw measurements**

## Scientific use and R&D

- As the observations are provided in a much more coarse form they can be used for **testing hardware and software solutions and for new post processing algorithms** e.g. for modelling **ionosphere or troposphere**.

## Increased accuracy

1

- **Subject to hardware limitations**, access to raw measurements means a developer can employ **advanced positioning techniques** (RTK, PPP) and create a solution currently only available in professional receivers.
- It results in a technological push to develop new applications.

## Integrity/Robustness

2

- Access to raw measurements will offer new ways to detect **RF interferences** and to locate the interference source by combining the measurements from multiple devices (crowdsourcing), or **verify the source** (OS-NMA).
- **SBAS corrections** can be incorporated without the need for additional equipment.

## Testing, performance monitoring and education

3

- Raw measurements can be used for **monitoring performance** (data, accuracy, Rx clock), testing and to compare solution from single constellations, eliminate specific satellites or test for worst scenario performance.
- **Education use** for understanding GNSS, Signal processing or orbits in smartphone is not negligible too.

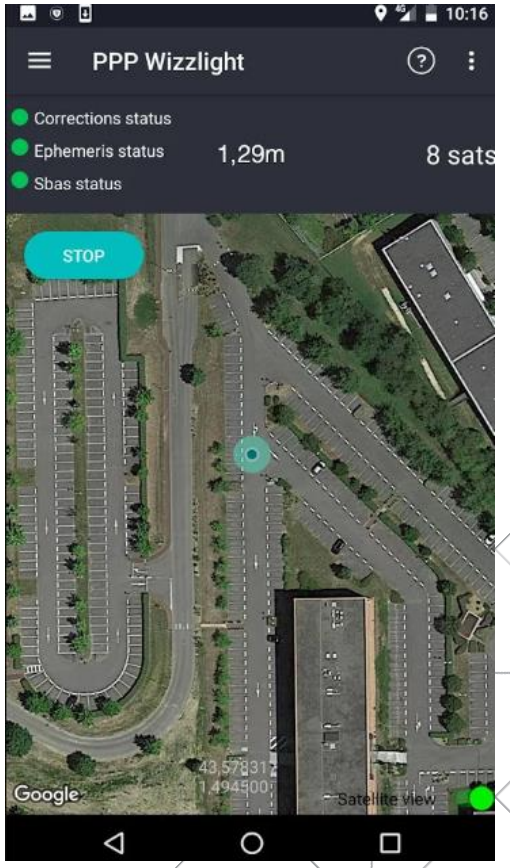
# 1 High accuracy apps

Example of app providing high accuracy: **PPP WizzLite**

- based on raw GNSS measurements, the app uses high level algorithms developed by the French Space Agency (CNES PPP-Wizard)

- Accuracies of 1-2 meters can be reached in kinematic mode and sub-meter in static mode

- To do so, users need to pull external RTCM streams **for orbits/clocks corrections and broadcasts**, such as ones available from the International GNSS Service Real-Time Service (IGS RTS)



# 2 Integrity/robustness: Galileo OS Navigation Message Authentication

"Navigation Message Authentication" is the ability of the system to guarantee to the users that they are utilising navigation data that has not been modified and comes from the Galileo satellites and not from any other source.

*Ref.* ***Galileo Navigation Message Authentication Specification for Signal-In-Space Testing – v1.0*** *(to be updated)*

- Clear **differentiator w.r.t. other GNSS** available to the civil community
- Fully **backward compatible**
- Disseminated on the first Galileo frequency (**E1B**)
- Contributes to **mitigate GNSS vulnerabilities**
- No need to store secret keys in the Rx, just public key
- Follows crypto standards and recommendations to be secure over the next decades

Can be used by apps in near future thanks to access to raw measurement navigation message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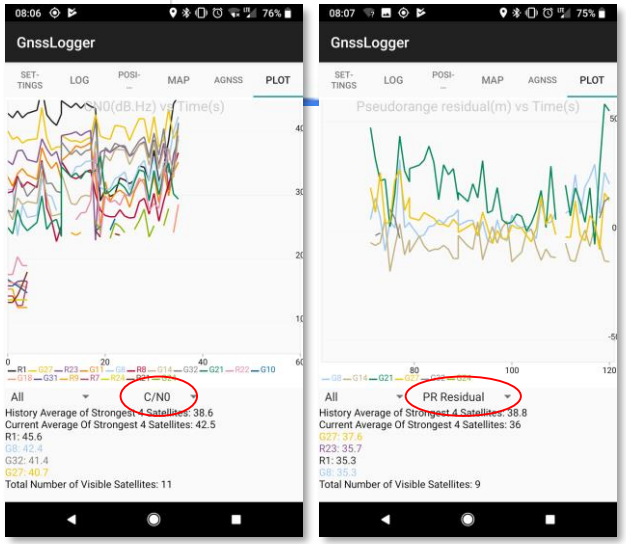
# Education/Testing: Logging and monitoring apps (1)

3

GNSS Logger:

- The **GNSS Analysis** reads the GPS/GNSS raw measurements collected by the **GNSS Logger app** and uses them to analyze the GNSS receiver behaviour
- The GNSS Analysis app is built on MATLAB, but you don't need to have MATLAB to run it. The app is compiled into an executable that installs a copy of the MATLAB Runtime






New in 2018:

- **duty cycling** control
- Analysis on the phone

# Education/Testing: Logging and monitoring apps (2)

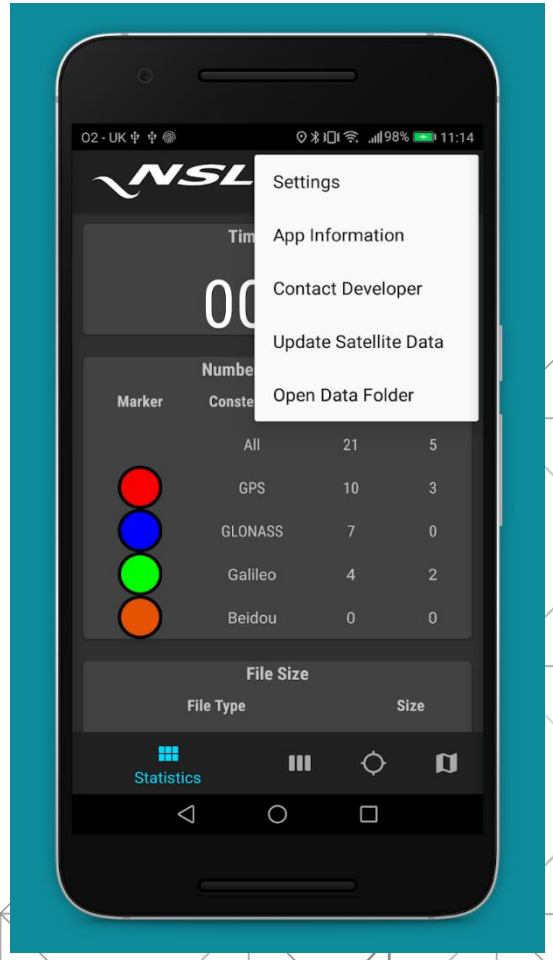
3

HORIZON 2020

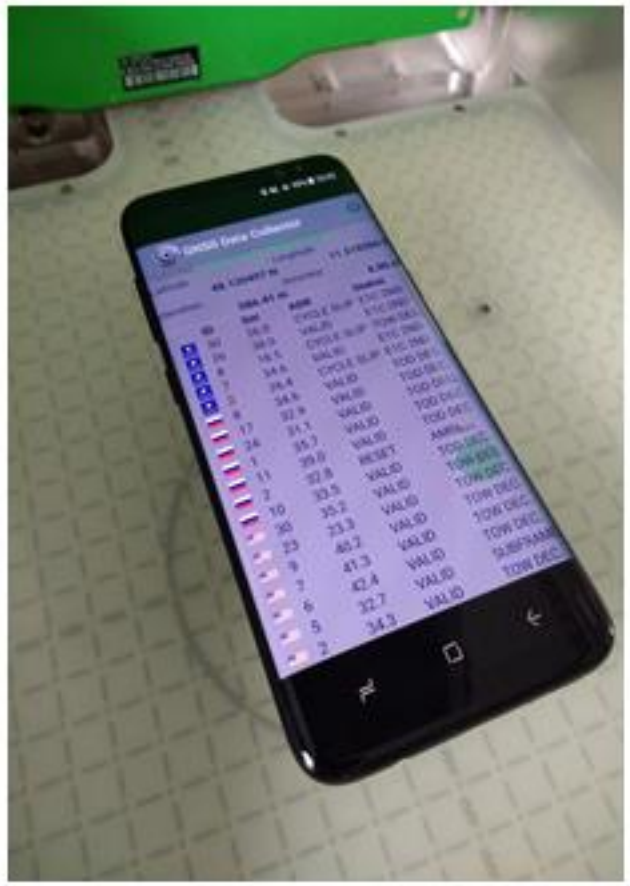
**RINEX ON**

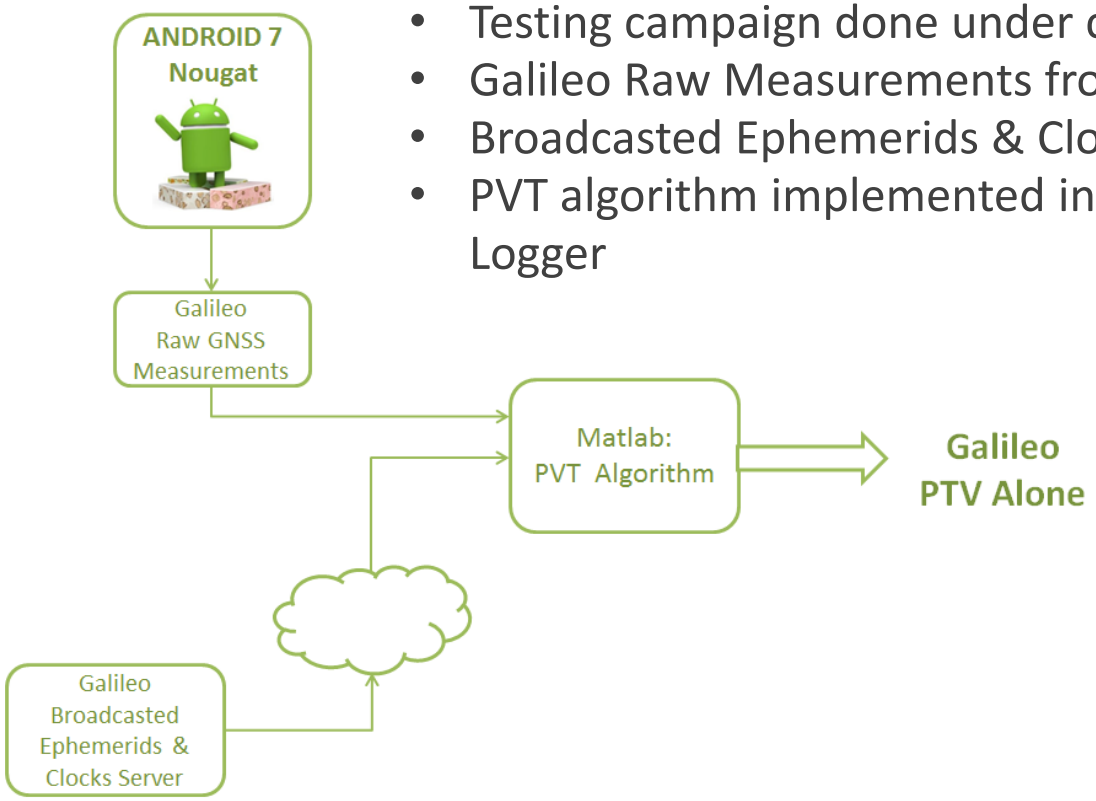
Written by NSL as part of the H2020 FLAMINGO project

- An ongoing development as the project progresses
- Includes:
  - RINEX Observation and Navigation Message File writer. Can choose constellations
  - GNSS skyplot and satellite planner in 24-hour timescale
  - Signal-to-noise (signal strength) graphic
  - Satellites tracked and measured monitor
  - File size monitor



# 3 Education/Testing: Outputs of GSA smartphone testing campaign (1)



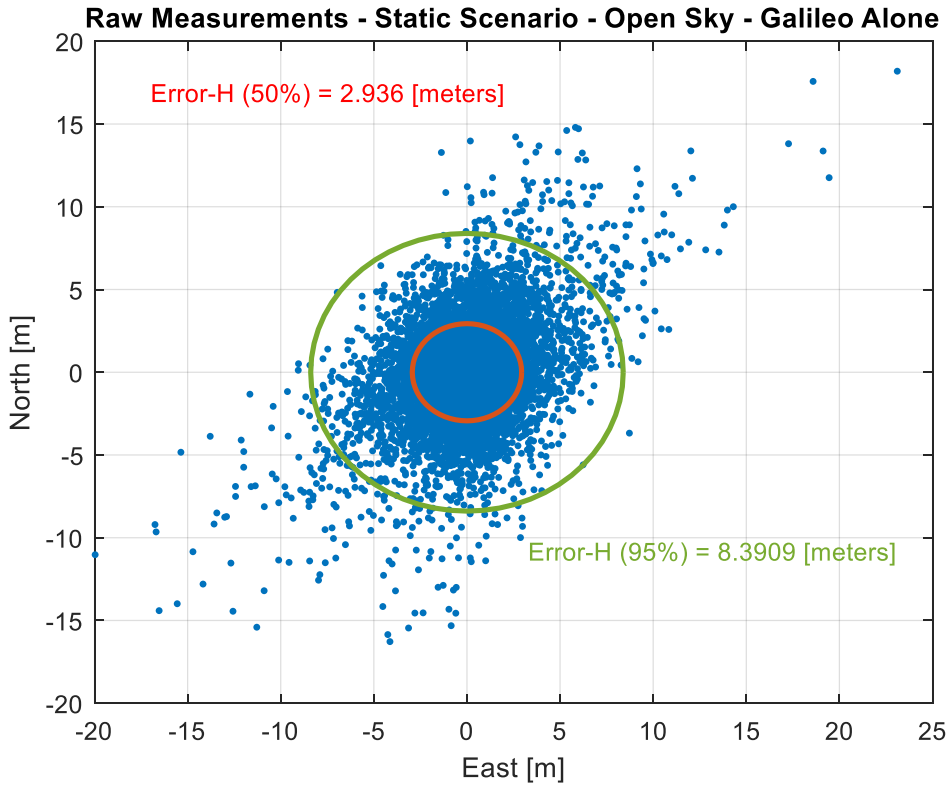


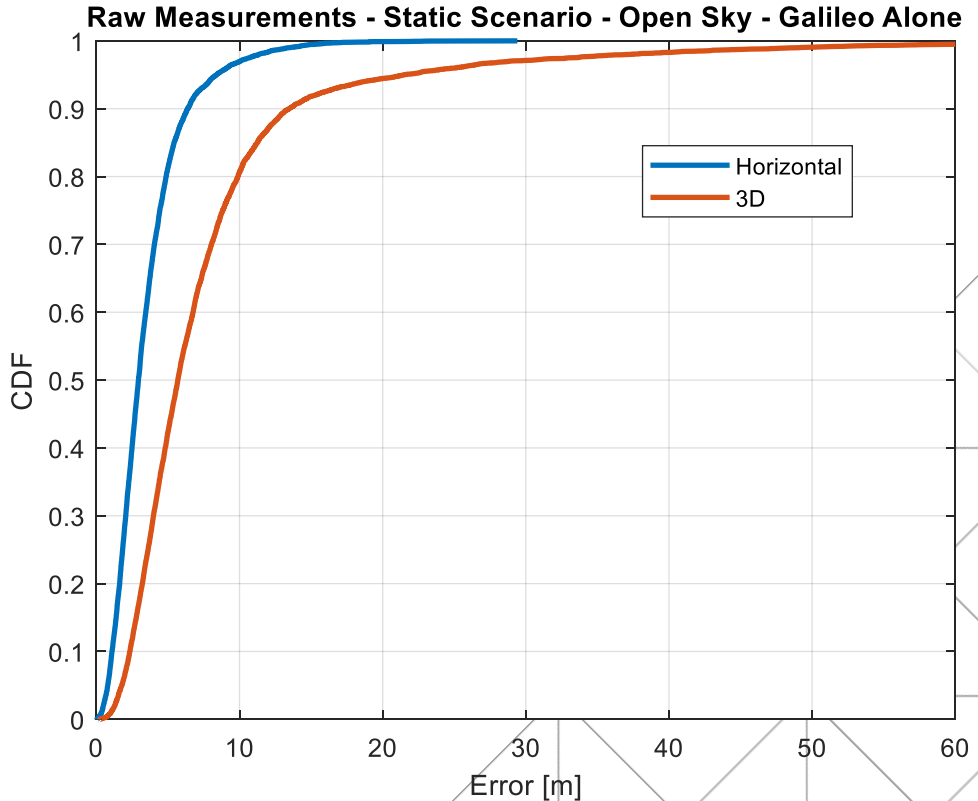

- Testing campaign done under contract with Airbus D&S
- Galileo Raw Measurements from Samsung S8
- Broadcasted Ephemerids & Clocks from Server (IGS)
- PVT algorithm implemented in Matlab, logging Airbus GNSS Logger

# 3 Education/Testing: Outputs of GSA smartphone testing campaign (2)

**Galileo-only PVT – Open Sky, Static**

- 5 Galileo Satellites used for the PVT solution
- 2.9 meters accuracy (50%)
- 8.4 meters accuracy (95%)

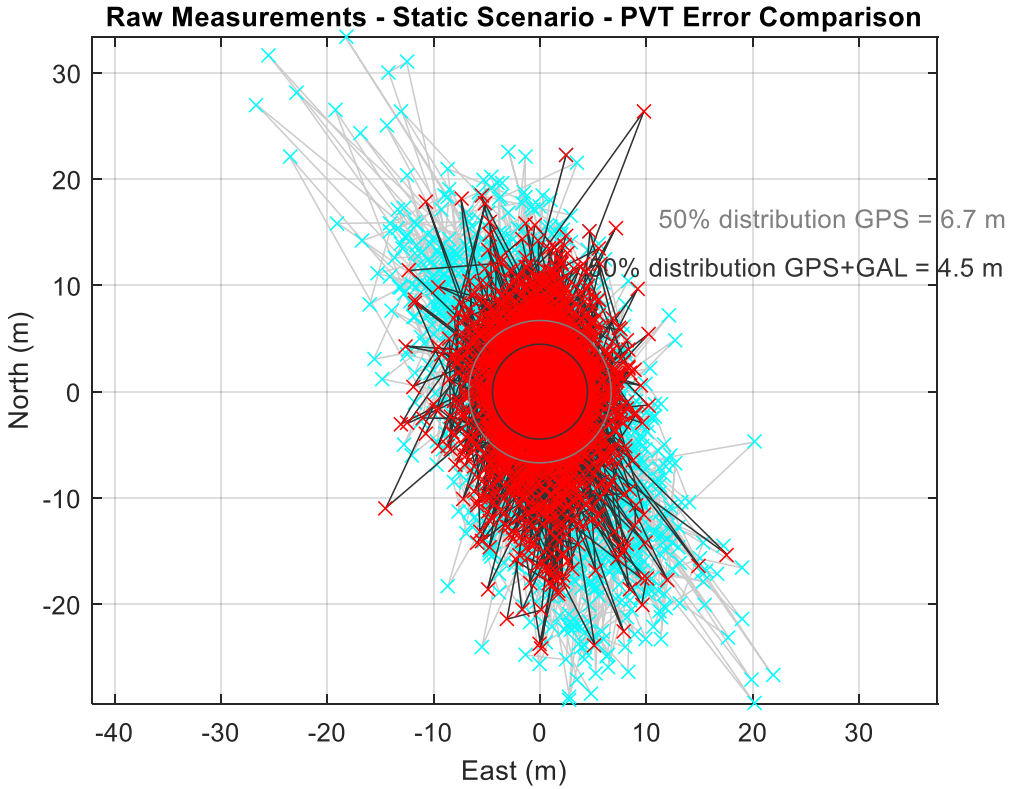


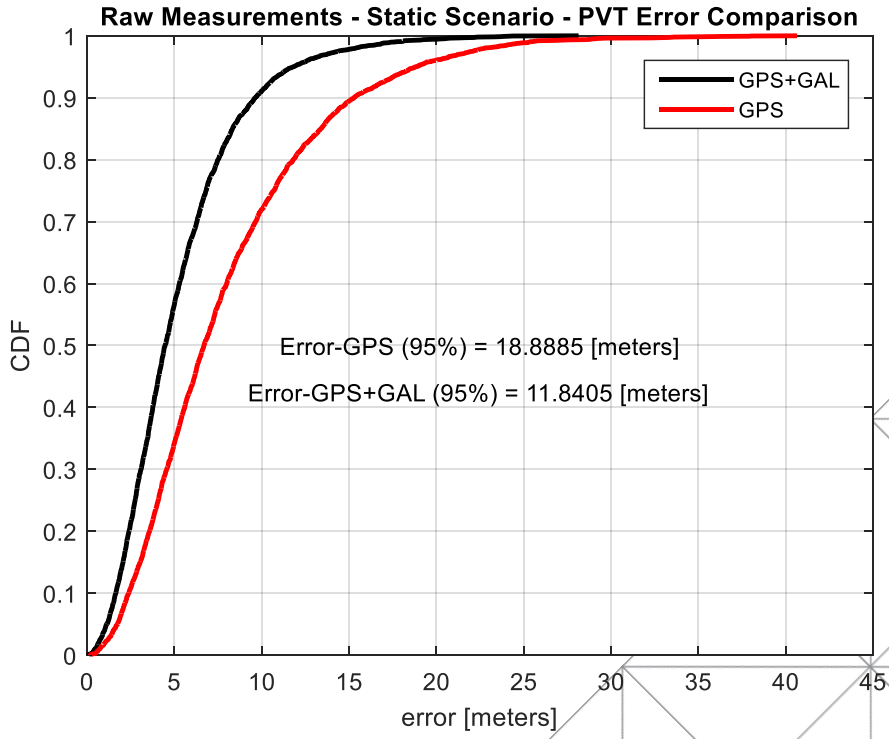



# 3 Education/Testing: Outputs of GSA smartphone testing campaign (3)

**GPS vs GPS + Galileo PVT - Open Sky, Static**

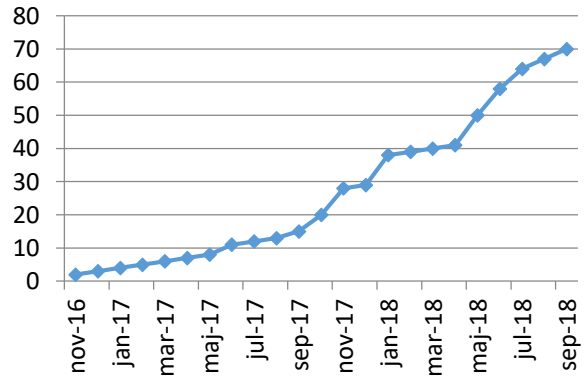
- 5 Galileo Satellites used for the PVT solution
  - GPS alone 6.7 meters error
  - **Galileo increases the accuracy up to 4.5 meters**



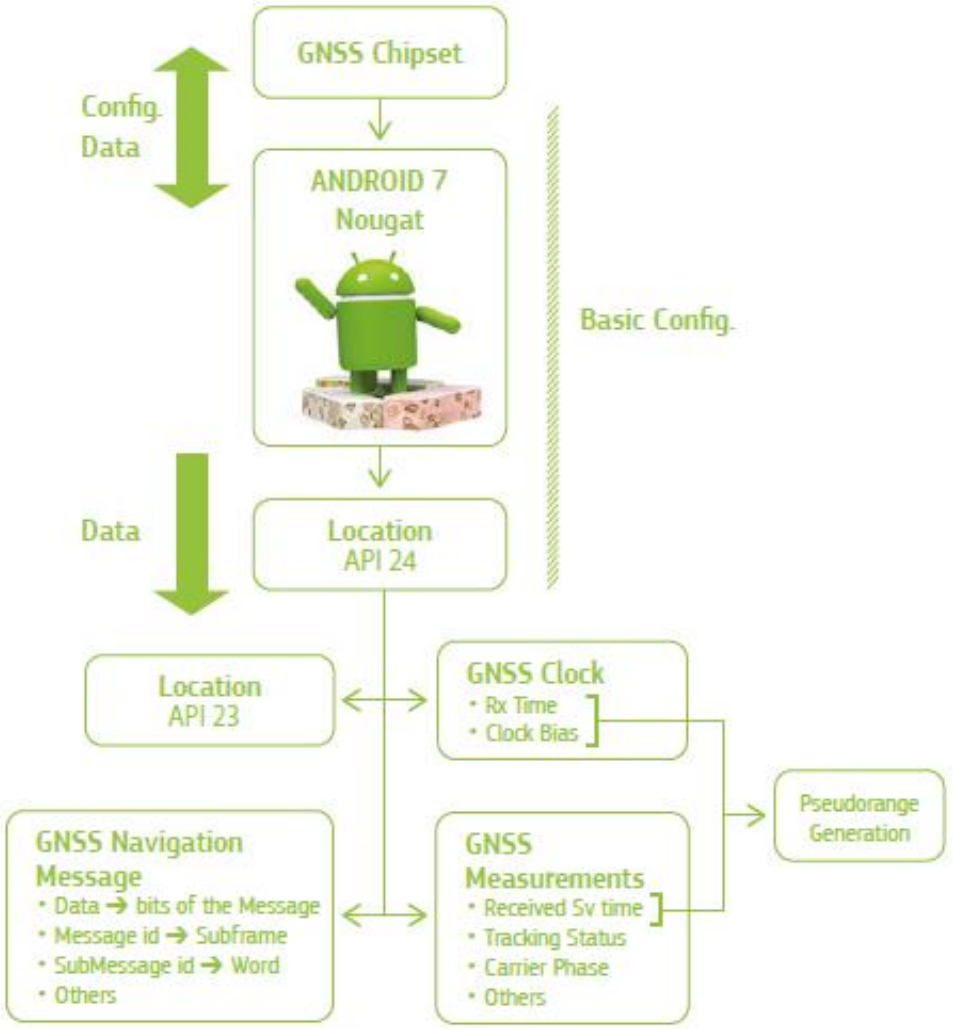



# Galileo is used today on the majority of professional devices and increasingly many consumer platforms


**Galileo-enabled smartphones**



# 3 Education/Testing: Outputs of GSA smartphone testing campaign (4)




Which satellites have been used in the PVT by phone?

Google Location class:

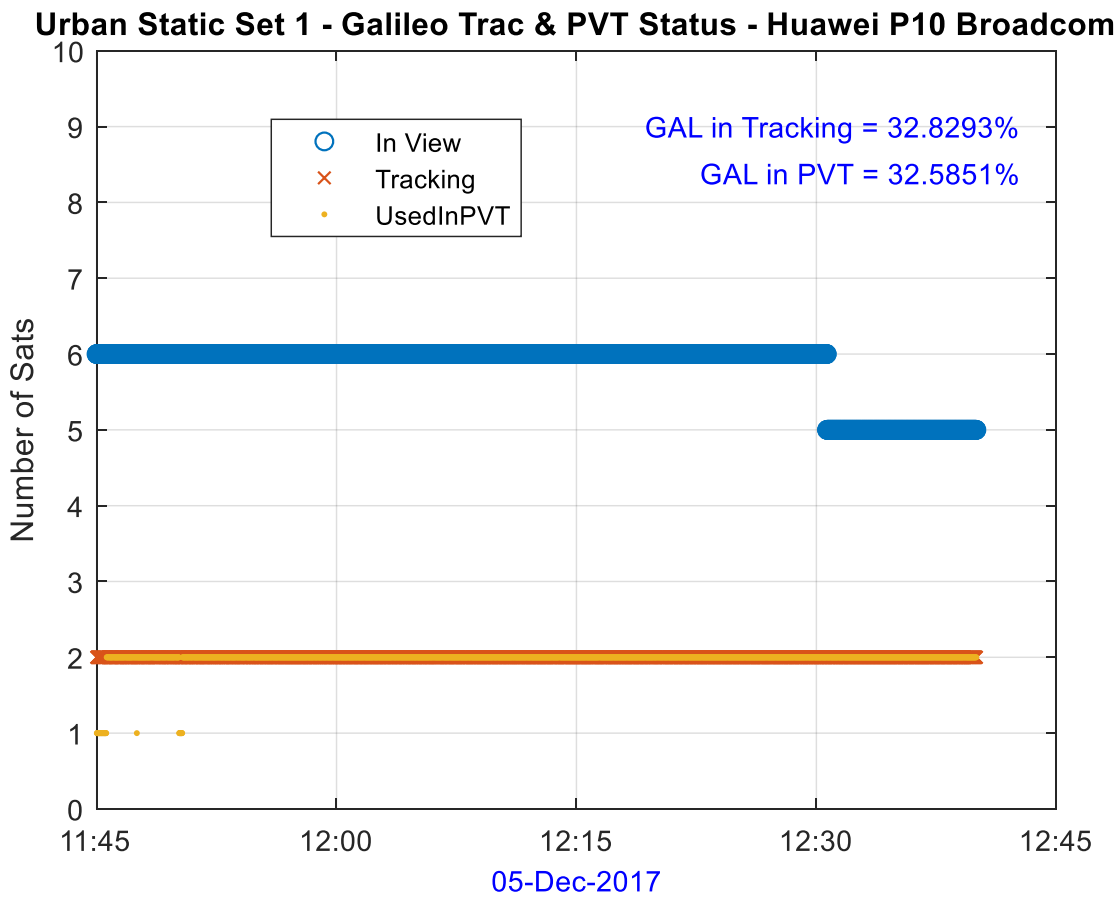
- Satellites used for PVT
- Ephemerids and almanac available

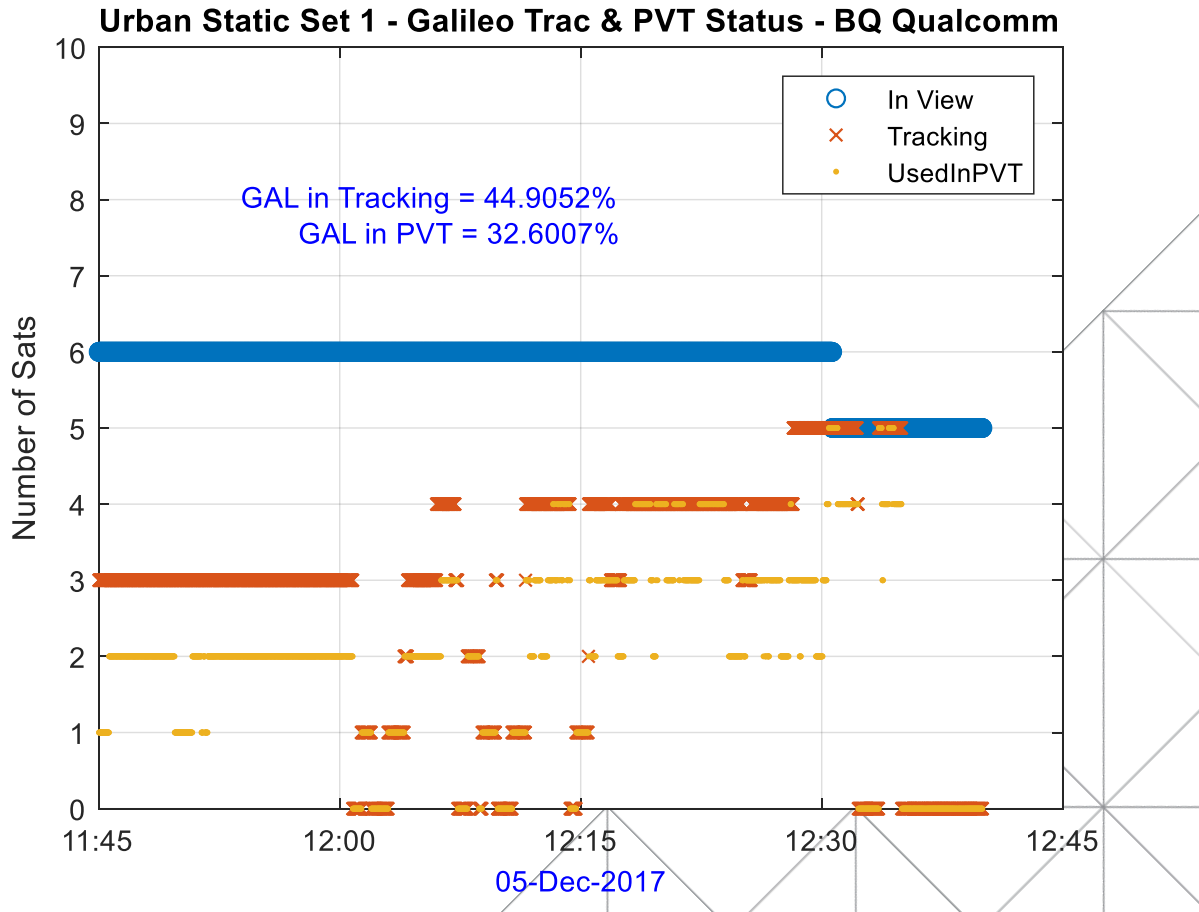
Analysis of Galileo usage by phone in PVT can be done

# 3 Education/Testing: Outputs of GSA smartphone testing campaign (5)

PVT & Tracking: **Percentage over the in-view healthy Galileo Satellites**

- Same scenario for both phones



# 3 Education/Testing: Outputs of GSA smartphone testing campaign (5)

PVT & Tracking: **Percentage over the in-view healthy Galileo Satellites**

Huawei P10:

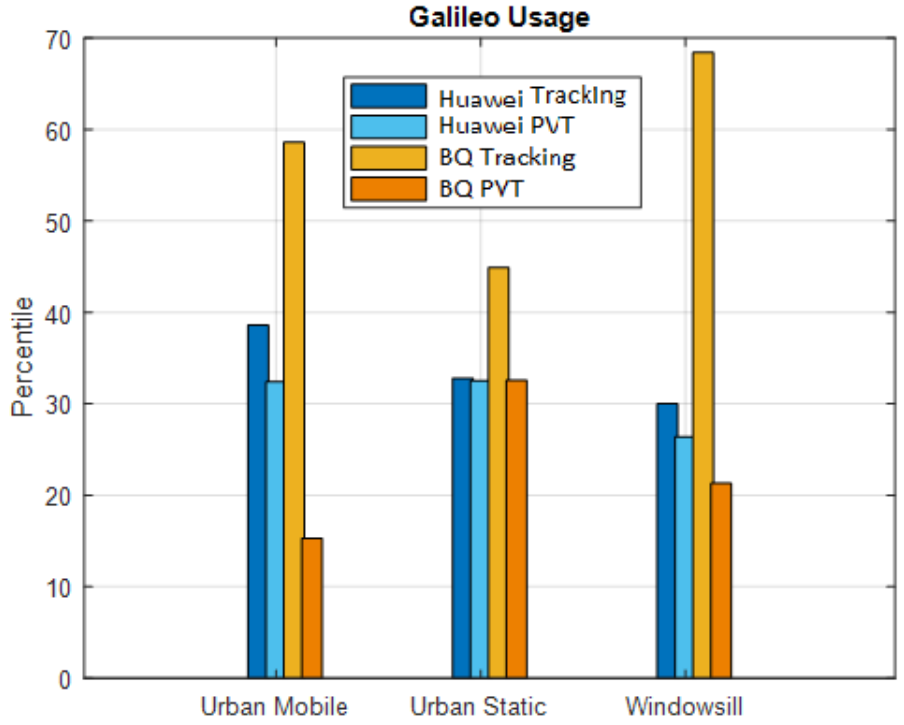
- Almost all the measurements are used in the PVT solution.
- Less than 40% of the measurements are tracked

BQ:

- More than 45% of the measurements are tracked in all the scenarios.
- Up to 70% of the measurements are tracked in the windowsill scenario
- The measurements used in PVT reduced

Comparison:

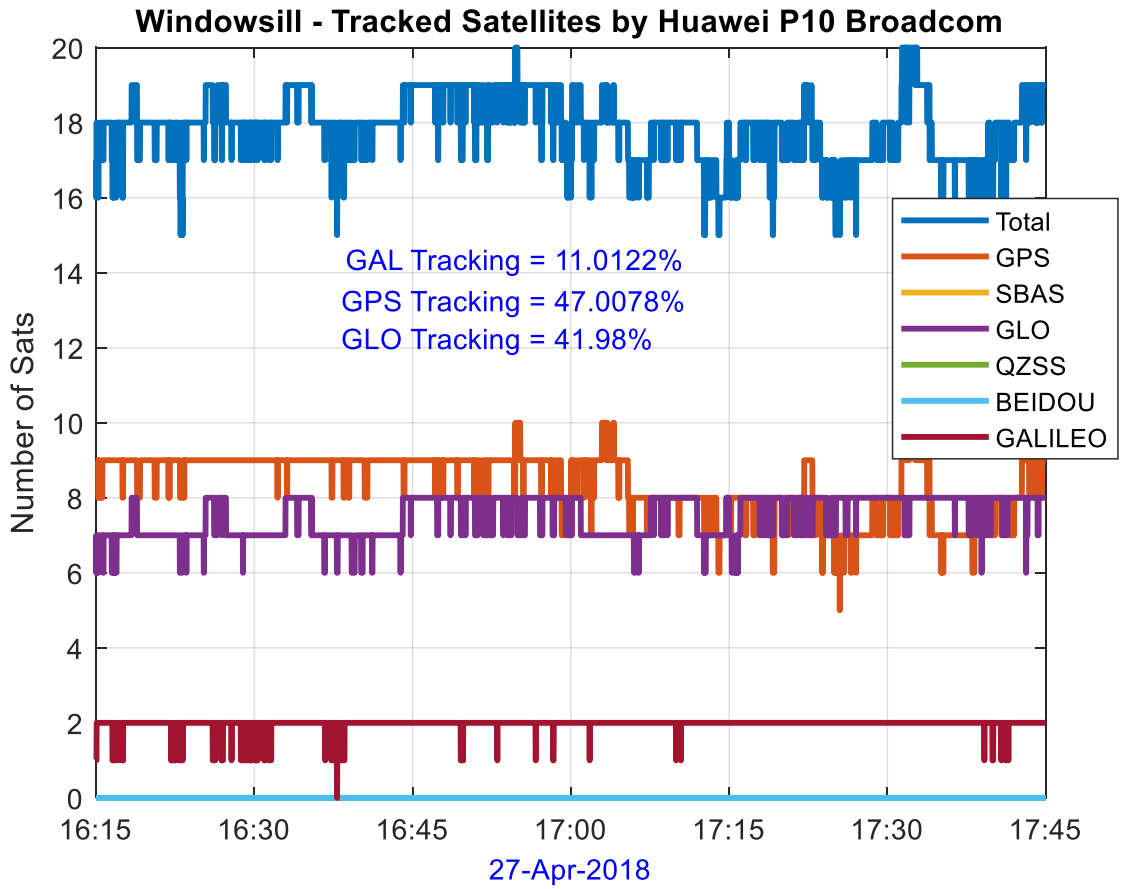
- Huawei uses a bit more of the Galileo measurements for the PVT solution
- BQ tracks almost 2 times more the Galileo satellites compared to Huawei

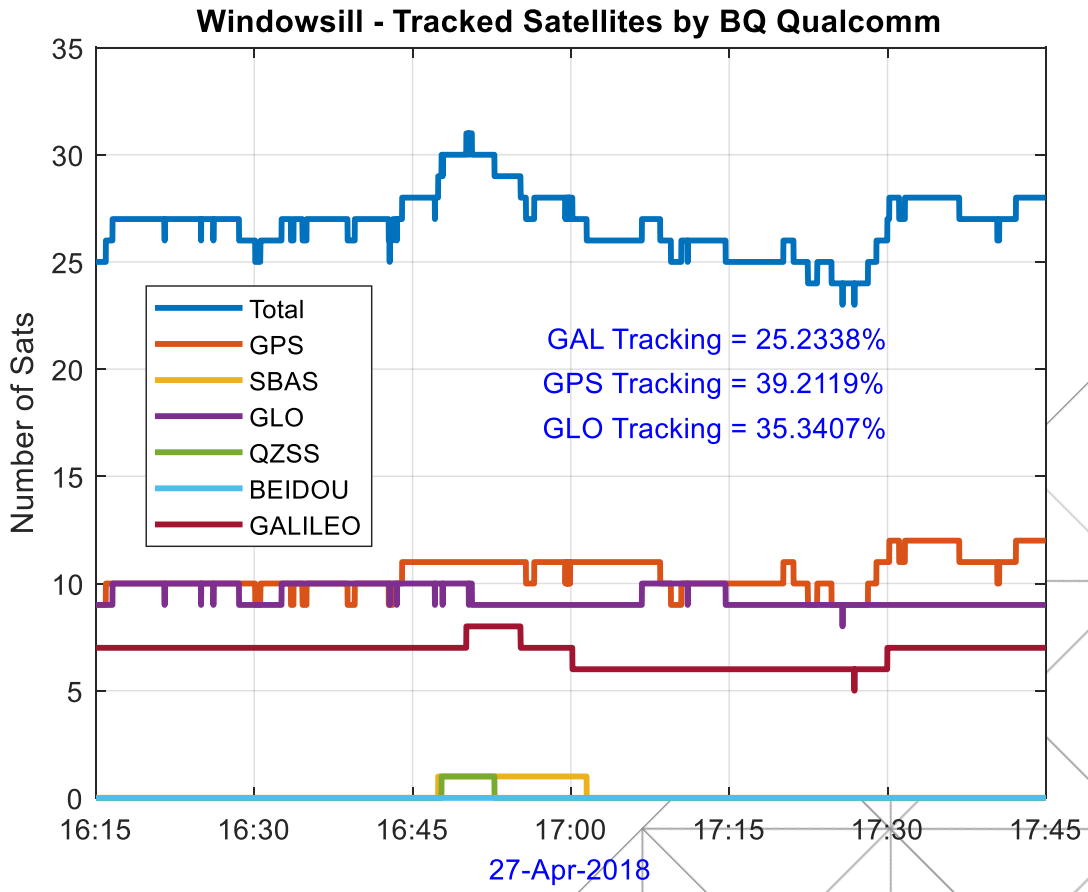


# 3 Education/Testing: Outputs of GSA smartphone testing campaign (6)

## Tracking per Constellation : Channel allocation per constellation

- Same Scenario for both phones



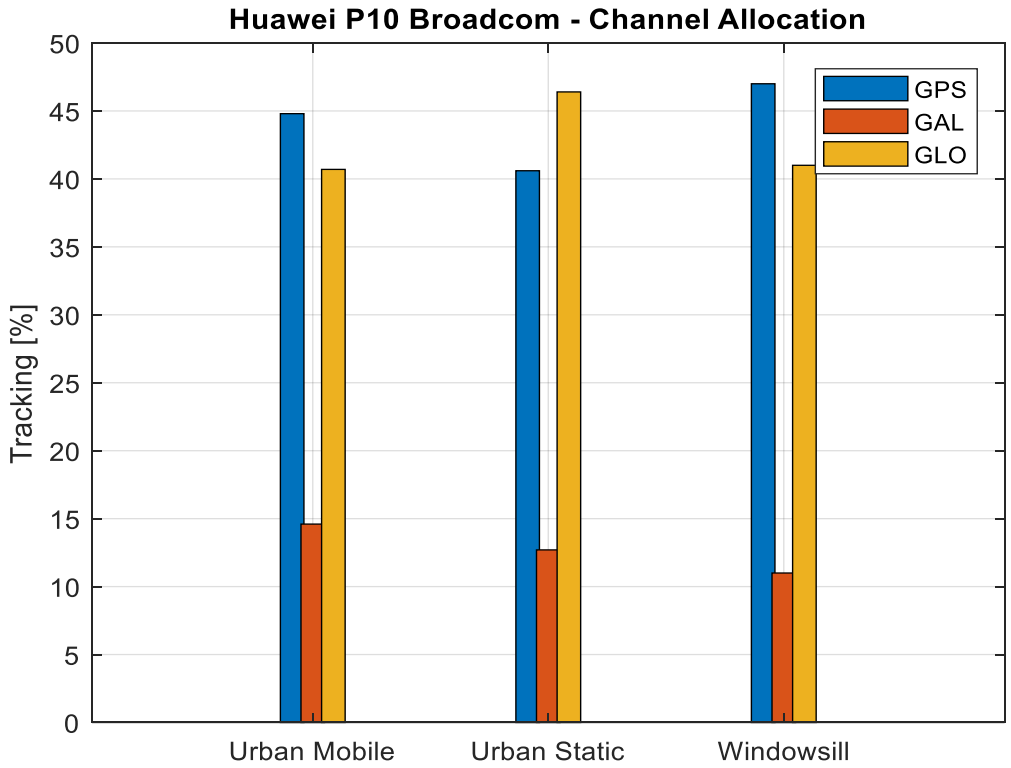
# 3 Education/Testing: Outputs of GSA smartphone testing campaign (7)

## Tracking per Constellation : Channel allocation per constellation

- Same Scenario for both phones

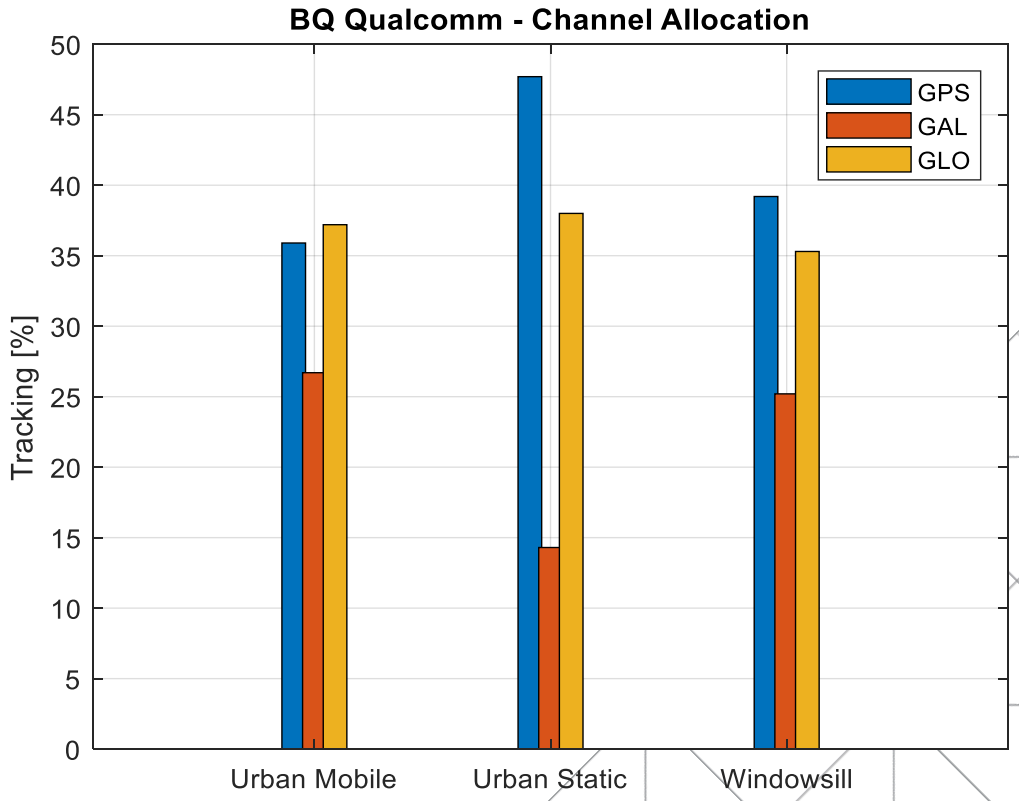
Huawei P10:

- **15%** of the channels track Galileo satellites




**BQ:**

- **28%** of the channels track Galileo satellites



# 3 Education/Testing: GNSS Compare

Winner of ESA`s Smartphone App competition 2018: **GNSS Compare**

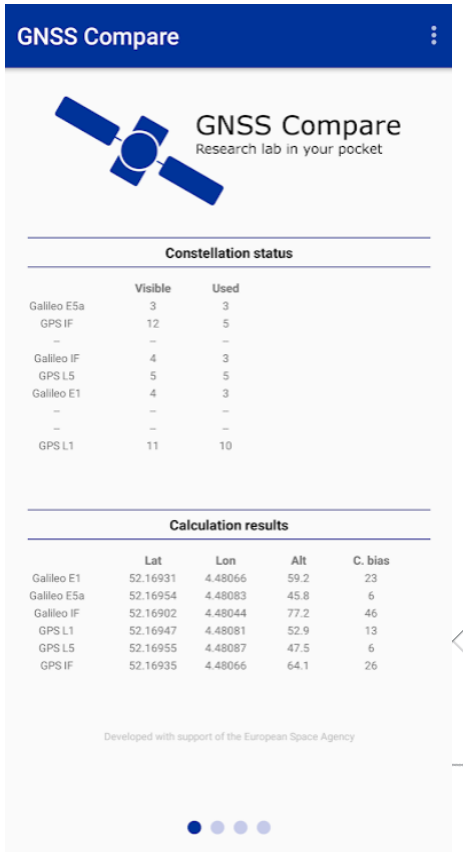
- “The purpose of GNSS Compare is to make the life of developers and researchers easier. It’s an easy to use and easy to extend Android-based framework for calculating the Position, Velocity and Time (PVT) based on the raw GNSS measurements”

- **Open source code on github**
  https://github.com/TheGalfins/GNSS_Compare

- Online documentation: https://gnss-compare.readthedocs.io

- Available PVT estimators: Weighted Least Squares, Extended Kalman Filter
  - Data logging formats: Simple Logger (UTC timestamp, X, Y, Z), NMEA (UTC timestamp, lat, lon, alt, CN0), Raw GNSS measurements (Google’s GnssLogger format)

- Supports dual-frequency

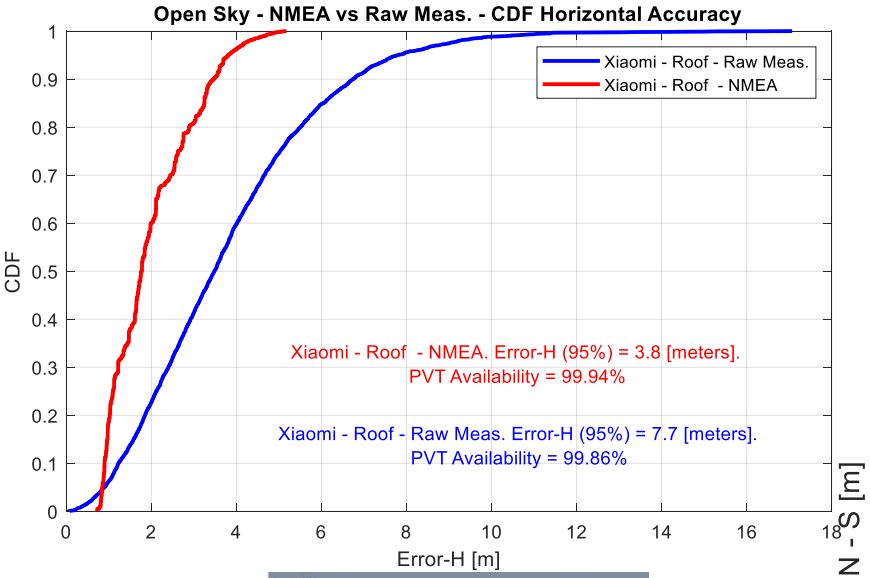


# Dual-frequency phones

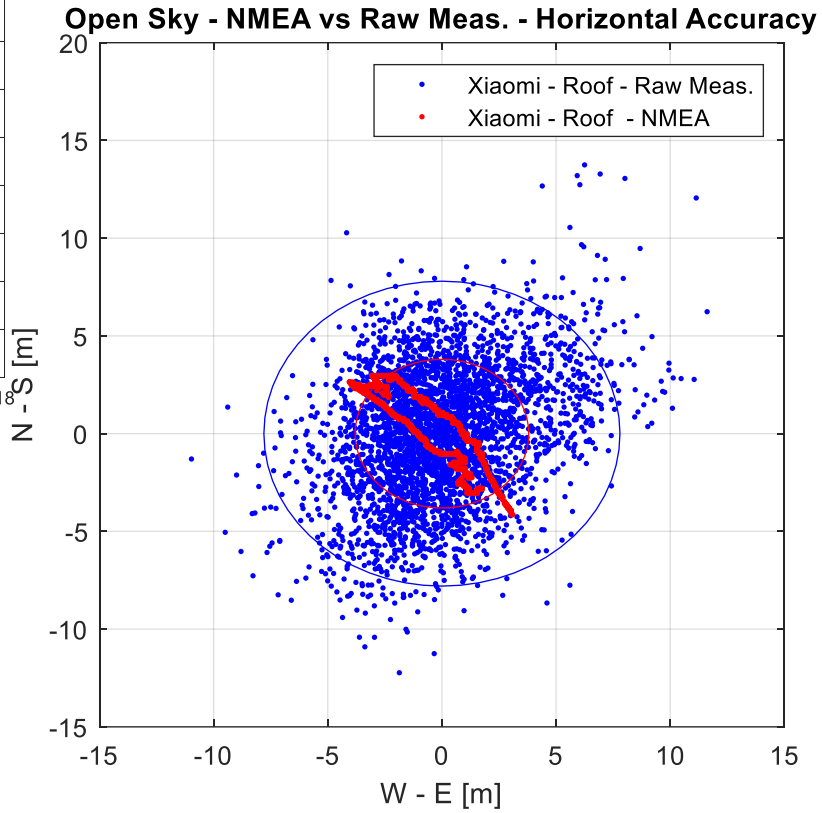
- Xiaomi`s world's first dual-frequency GNSS smartphone Mi8
- Fitted with a Broadcom BCM47755 chip
- launched on May 31 2018
- the world's first smartphone providing below meter accuracy for location-based services and vehicle navigation
- Raw measurements can help to provide even higher accuracy
- Use L1/E1 and L5/E5 frequencies

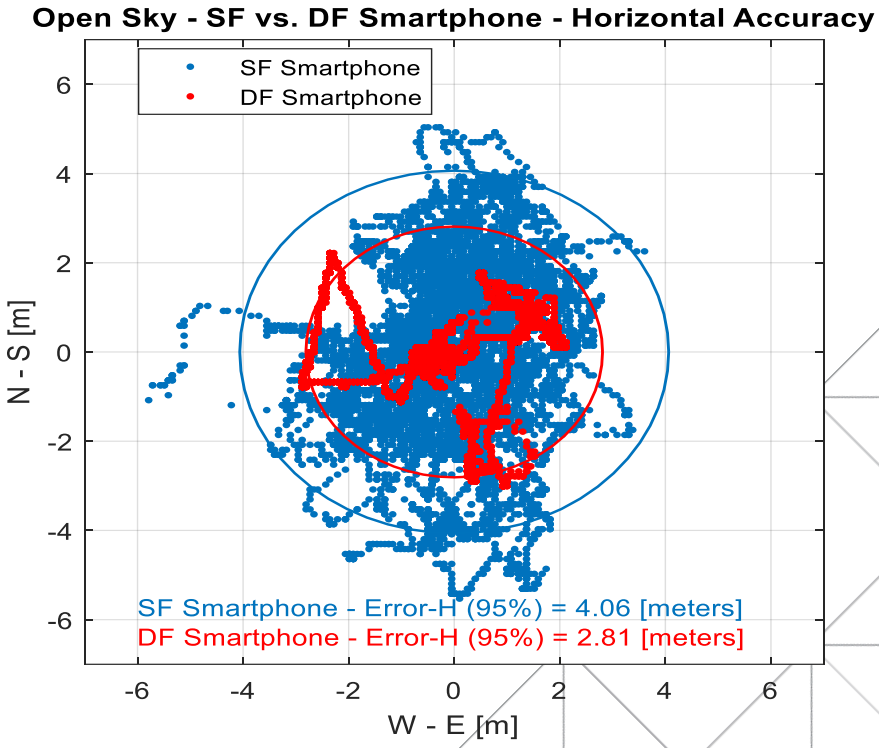

- Huawei`s  first dual frequency GNSS smartphone Mate 20 Pro
- Fitted with the Broadcom BCM47755 chip too
- launched on November 2018

# Some results of the dual-frequency smartphone







# GSA Task Force: created shortly after Google`s announcement

- **The GSA GNSS Raw Measurements Task Force** was established following the announcement of Google in 2016 to make the Android Raw Measurements available from Android 7.0

  - Continuously open call for participation (write to market@gsa.europa.eu )
  - No fee for membership

- **Objective(s):**

  -“to share knowledge and expertise on Android raw measurements and its wider use, including its potential for high accuracy positioning techniques”

  - **“**valorise the Galileo differentiators”

# GSA Task Force: Short history


*Task force has more than 100 members (these are "founding" ones)*

- The Task Force includes GNSS experts, scientists and GNSS market players

- First workshop took place in July 2017 (over 30 participants)
  - Meeting served as a **brainstorming event** for what later became the White Paper
- Testing results of some members were presented during ION 2017 conference in Portland, USA
- Second workshop in May 2018 in Prague


GNSS raw measurements in consumer devices

A playground for scientists or a real market opportunity?

Join the session for an interactive discussion with **Frank van Diggelen** (Google), **Mark Dumville** (NSL), **Moises Navarro** (Astrium) and **Lukasz Bonenberg** (University of Nottingham) and preview the GSA Raw Measurements Task Force White Paper.

Thursday, September 28, 2017 | 2:00 p.m. - 2:45 p.m. | Room C120-122

With a smartphone featuring Android 7.0 (i.e., Nougat), users now have access to raw GNSS measurements. This feature opens the door to higher-accuracy and the development of algorithms once restricted to more advanced GNSS receivers. This new capability will allow users to fully benefit from the special features offered by Galileo, and to combine it with other constellations in the most efficient way.

Although Nougat makes accessing raw data easier, using it remains a challenge. In fact, its use remains largely limited to research centres, universities and GNSS experts – which raises the question: is there real market opportunity in GNSS raw measurements or is it simply a playground for scientists and experts?

To answer this question, the European GNSS Agency (GSA) launched the Raw Measurements Task Force. Comprised of GNSS experts, scientists and market players, the Task Force aims to foster a wider use of these raw measurements. Their White Paper, set to be published soon, will provide application developers with a range of tools, including practical tips and innovative ideas on how to take full advantage of GNSS raw measurements.

To discover smartphones and other devices that are already Galileo-enabled go to: www.useGalileo.eu

**A sneak peek at ION**

This exclusive session will include:

- First-hand tips and innovative ideas on using GNSS raw measurements
- Results from tests using raw measurements conducted by different experts
- Advice on how to ensure the use of Galileo in smartphone applications
- Expert insights on the challenges and opportunities of GNSS raw measurements

The session will be moderated by Fiammetta Diani, Deputy Head of Market Development at the European GNSS Agency (GSA).

www.gsa.europa.eu

GALILEO

LINKING SPACE TO USER NEEDS

# GSA Task Force: Galileo Raw measurements White Paper published in January 2018


**Part I**: overview of the theoretical basics needed to reconstruct GNSS raw measurements using Android, including a basic overview of GNSS, GNSS time references, pseudoranges, navigation messages and position estimation

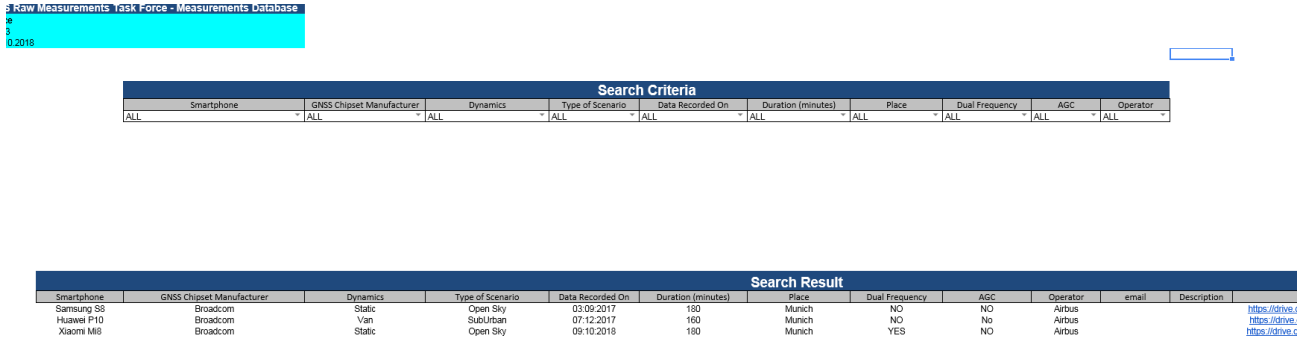
**Part II**: information on how to access and use raw measurements, including generating pseudoranges and Doppler

**Part III**: a look at the most promising techniques and discussion on the benefits and limitations of each technique

**Part IV**: use cases that may benefit from the increased accuracy and integrity obtained with the use of GNSS raw measurements

# GSA Task Force: Discussion Forum and Measurements Database

- Discussion Forum set up for the TF members
  - http://rawmeasurementstaskforce.forums-free.com
- Database of measurements at Google Docs
  - https://docs.google.com/spreadsheets/d/1Li4aKf43eJipZGweWpEIRHaRgj4tSacZ9WNuPHObt88/copy

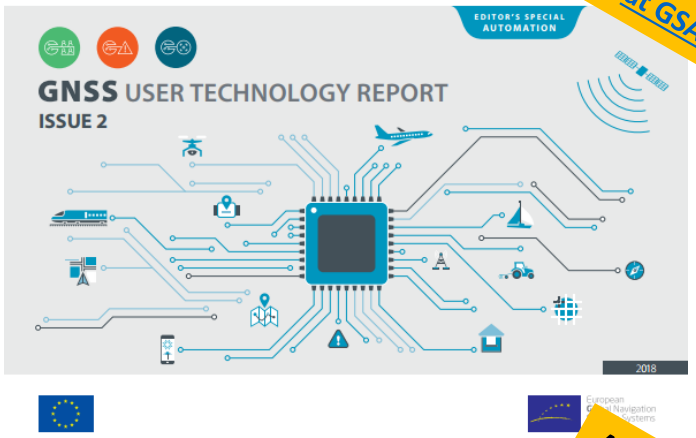



# The second issue of the GNSS User Technology Report, a publication on user technology

**2nd edition of GSA`s GNSS User Technology Report (Sept 2018)**

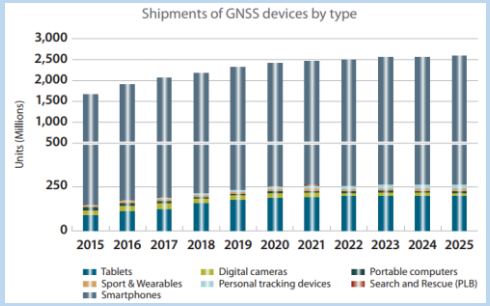
- General overview of the latest GNSS receiver technology common to all application areas
- An in-depth analysis of GNSS user technology as it pertains to three key macrosegments:
  - ✓ Mass market solutions
  - ✓ Transport safety and liability-critical solutions
  - ✓ High precision, timing and asset management solutions
- Editor's special on Automation and increasingly important role of GNSS

Available for download at GSA website




**5th edition of GSA`s GNSS Market report (May 2017)**

- GNSS market overview
- Macrotrends impacting GNSS across market segments
- For each of eight segments:
  - ✓ market segment updates, opportunities and trends
- Editor's special on Drones




Available for download at GSA website

# Linking space to user needs

How to get in touch:

www.GSA.europa.eu

EGNOS-portal.eu

GSC-europa.eu

UseGalileo.eu