Performance analysis of GPS+Galileo smartphone raw measurements

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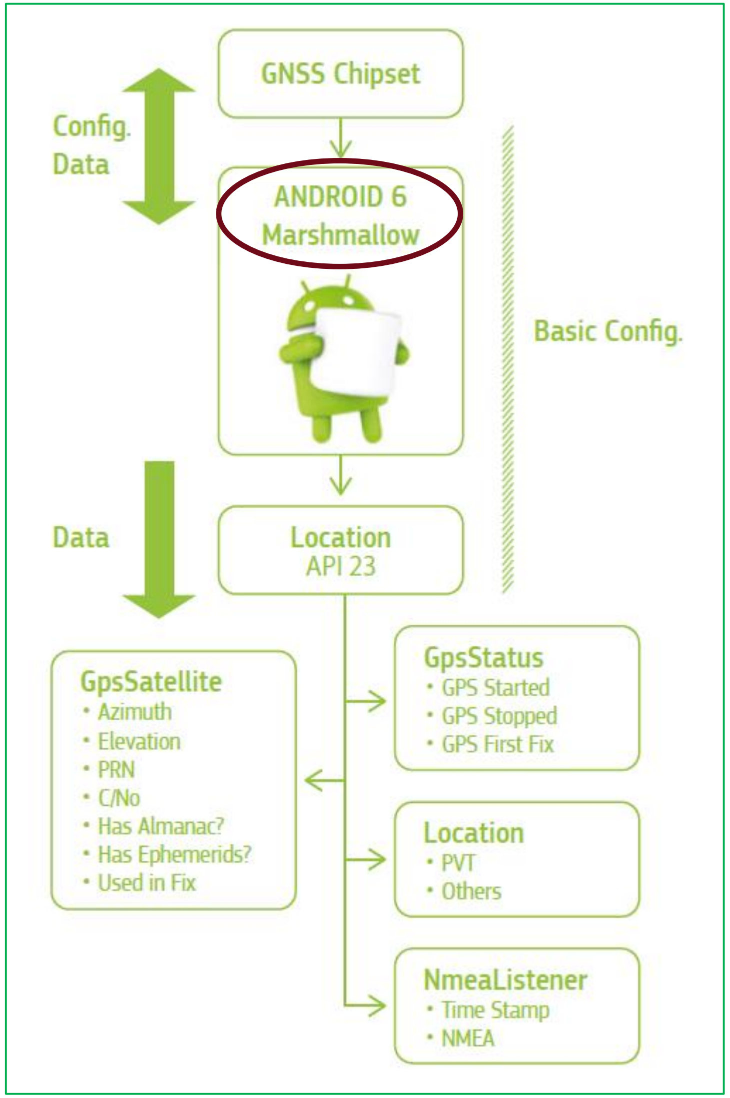
Agenda

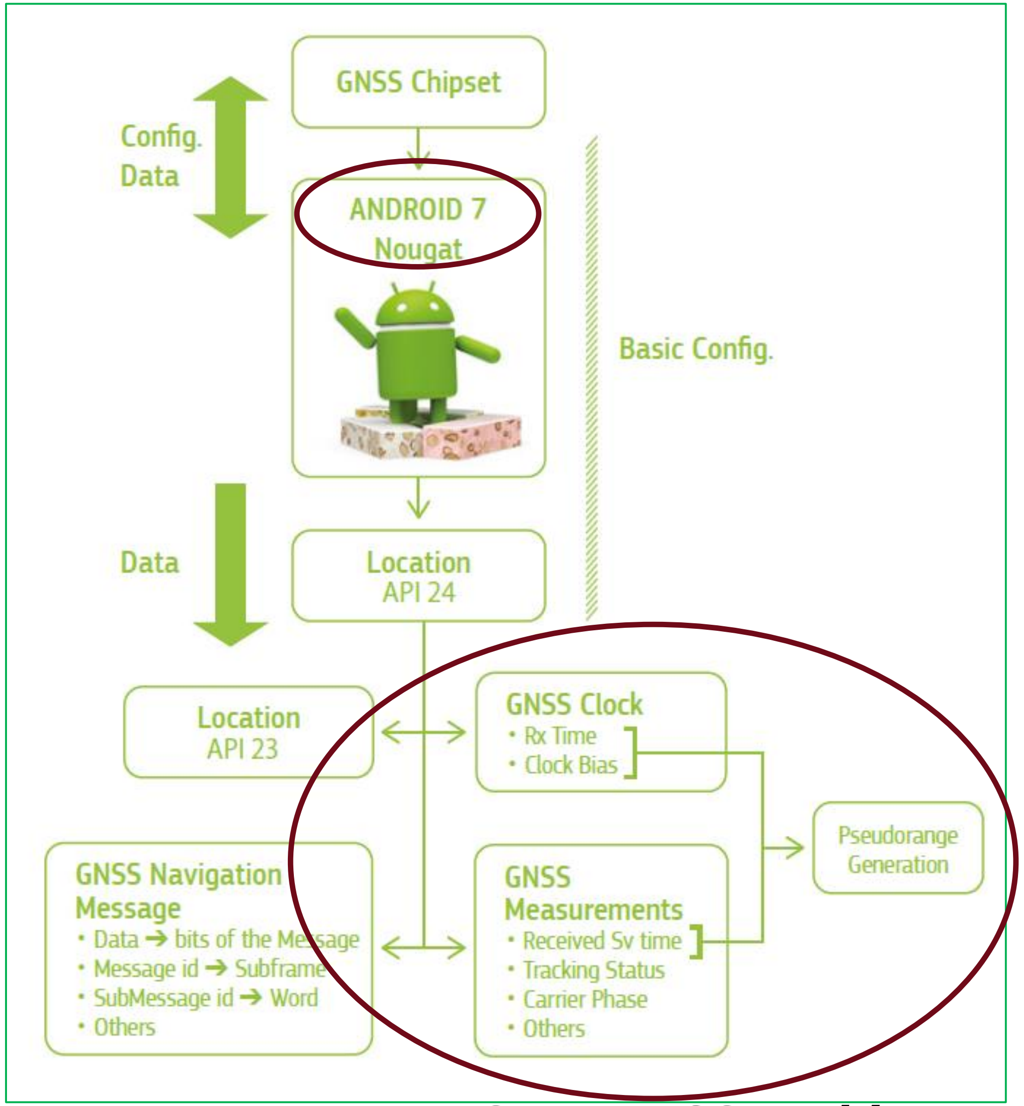
- Objectives
- Access to GNSS Raw Measurements using ANDROID APIs
- Smartphones' Configuration
- Scenarios' description
  - Static, Urban Pedestrian, Gesture, Sub-urban Vehicle and Aircraft.
- Results with
  - Carrier-phase differential approach (static and Kinematic);
  - Carrier-phase variometric approach: VADASE.
- Snapshot of the app MentorAge GNSS
- Conclusion and way ahead

Objectives

- Investigating on the quality of smartphones' GNSS measurements.
- Providing preliminary performance with consolidated positioning algorithms.
- Introducing the ***variometric*** approach with **VADASE** applied to smartphones.
- Identifying solutions and new applications with smartphones' GNSS measurements.
- Provide feedbacks.

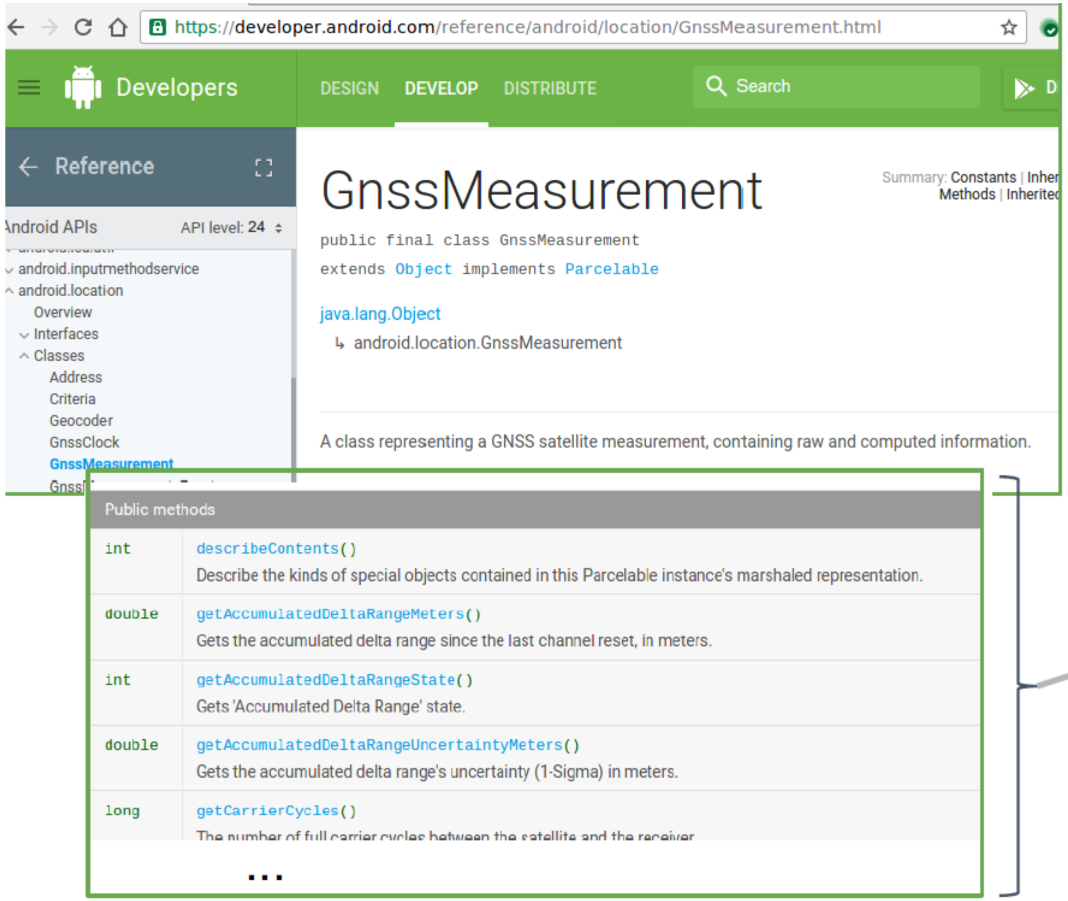
Access to GNSS Raw Measurements using ANDROID APIs





Source: GSA White Paper

Access to GNSS Raw Measurements using ANDROID APIs



Selected Public methods

- getAccumulatedDeltaRangeMeters()
- getCarrierCycles()
- getCarrierFrequencyHz()
- getCarrierPhase()
- getCn0DbHz()
- getConstellationType()
- getPseudorangeRateMetersPerSecond()
- getReceivedSvTimeNanos()
- getSnrInDb()
- getSvid()

Source: developer.android.com

Access to GNSS Raw Measurements using ANDROID APIs

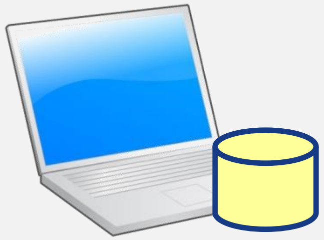
Android 7 Location - Clock and Measurements		
ANDROID CLASS	FIELD	DESCRIPTION
GNSSClock	*TimeNanos*	GNSS receiver's internal hardware clock value in nanoseconds
GNSSClock	*BiasNanos*	Clock's sub-nanosecond bias
GNSSClock	*FullBiasNanos*	Difference between TimeNanos inside the GPS receiver and the true GPS time since 0000Z, 6 January 1980
GNSSClock	*DriftNanosPerSecond*	Clock's drift
GNSSClock	*HardwareClockDiscontinuityCount*	Count of hardware clock discontinuities
GNSSClock	*LeapSecond*	Leap second associated with the clock's time
GNSSMeasurement	*ConstellationType*	Constellation type
GNSSMeasurement	*Svid*	Satellite ID
GNSSMeasurement	*State*	Current state of the GNSS engine
GNSSMeasurement	*ReceivedSvTimeNanos*	Received GNSS satellite time at the measurement time
GNSSMeasurement	*AccumulatedDeltaRangeMeters*	Accumulated delta range since the last channel reset
GNSSMeasurement	*Cn0DbHz*	Carrier-to-noise density
GNSSMeasurement	*TimeOffsetNanos*	Time offset at which the measurement was taken in nanoseconds
GNSSMeasurement	*CarrierCycles*	Number of full carrier cycles between the satellite and the receiver
GNSSMeasurement	*CarrierFrequencyHz*	Carrier frequency at which codes and messages are modulated
GNSSMeasurement	*PseudorangeRatemetersperSecond*	Gets the Pseudorange rate at the timestamp

Source: GSA White Paper

Smartphones’ Configurations

Huawei P10

Samsung S8



- **Rinex Converter**
- **Data Processing**
  - ✓ **RTKlib**
  - ✓ **VADASE**

RINEX Example

Live data - Static

```
QCOM2RINEX          Gabriele Pirazzi    20170817 205211     PGM / RUN BY / DATE
Qualcomm                                                    MARKER NAME
                                                            MARKER NUMBER
                                                            MARKER TYPE
                                                            OBSERVER / AGENCY
Qualcomm            Prototype           GEN9C               REC # / TYPE / VERS
Unknown             Unknown                                 ANT # / TYPE
        0.0000        0.0000        0.0000                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G    4 C1C L1C D1C S1C                                      SYS / # / OBS TYPES
E    4 C1X L1X D1X S1X                                      SYS / # / OBS TYPES
CARRIER PHASES NOT ALIGNED                                  COMMENT
G L1C                                                       SYS / PHASE SHIFT
E L1X                                                       SYS / PHASE SHIFT
     1.000                                                  INTERVAL
     1.000                                                  INTERVAL
  2016     8     4    11    35   24.3950000     GPS         TIME OF FIRST OBS
  2016     8     4    17    43    4.3940001     GPS         TIME OF LAST OBS
DBHZ                                                        SIGNAL STRENGTH UNIT
                                                            END OF HEADER
                        OMISSIS
> 2016  8  4 15 35 40.3950000  0 17
G 1  22929573.890  -14710760.105       3020.301         43.500
G 8  20485989.842  -26763234.862        249.751         49.000
G10  21352610.688  -23700721.931      -1419.249         50.300
G11  21872368.978  -20439829.530       2819.851         47.500
G14  25059157.998   -3812978.755       3198.551         39.300
G16  25022879.826   15892348.327      -3881.299         40.400
G18  23850858.900   -5068656.665      -2813.649         42.700
G22  24580371.770   -4649776.702       3608.601         42.200
G27  21225545.459  -14892683.567      -2197.599         47.700
G28  24752881.337   -7044161.808       2673.551         44.400
G30  25465884.640    -532597.453      -2204.899         34.700
G32  23856984.259  -10561157.132       2855.601         42.800
E 9  25045501.562  -12599064.211       3076.601         41.900
E11  23271265.633    1602356.816       -934.249         43.000
E12  27792245.324    8942067.559      -2525.399         36.700
E19  26591875.427    4330506.011      -1925.049         40.200
E30  27347563.770   -5297485.449        409.401         41.000
```

Carrier-phase

Code-phase

Doppler

CN_0

12 GPS satellites

5 Galileo satellites

Scenarios' description

Ref.	Device	Scenario	Type	Antenna	Duration	GNSS available	Algorithm
T-1	Huawei P10	Live	Static	Embedded	5 min	GPS+GAL	- Carrier Phase Differential (Static), Baseline~5Km - Variometric
T-2			Pedestrian	Embedded	5 min	GPS+GAL	- Variometric
T-3			Gesture	Embedded	5 min	GPS+GAL	- Variometric
T-4			Vehicle sub-urban	Embedded	5 min 3 sessions	GPS+GAL	- Carrier Phase Differential (Kinematic), Baseline~4Km - Variometric
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

T-1 scenario
Huawei P10 2D accuracy in live Carrier-Phase static scenario

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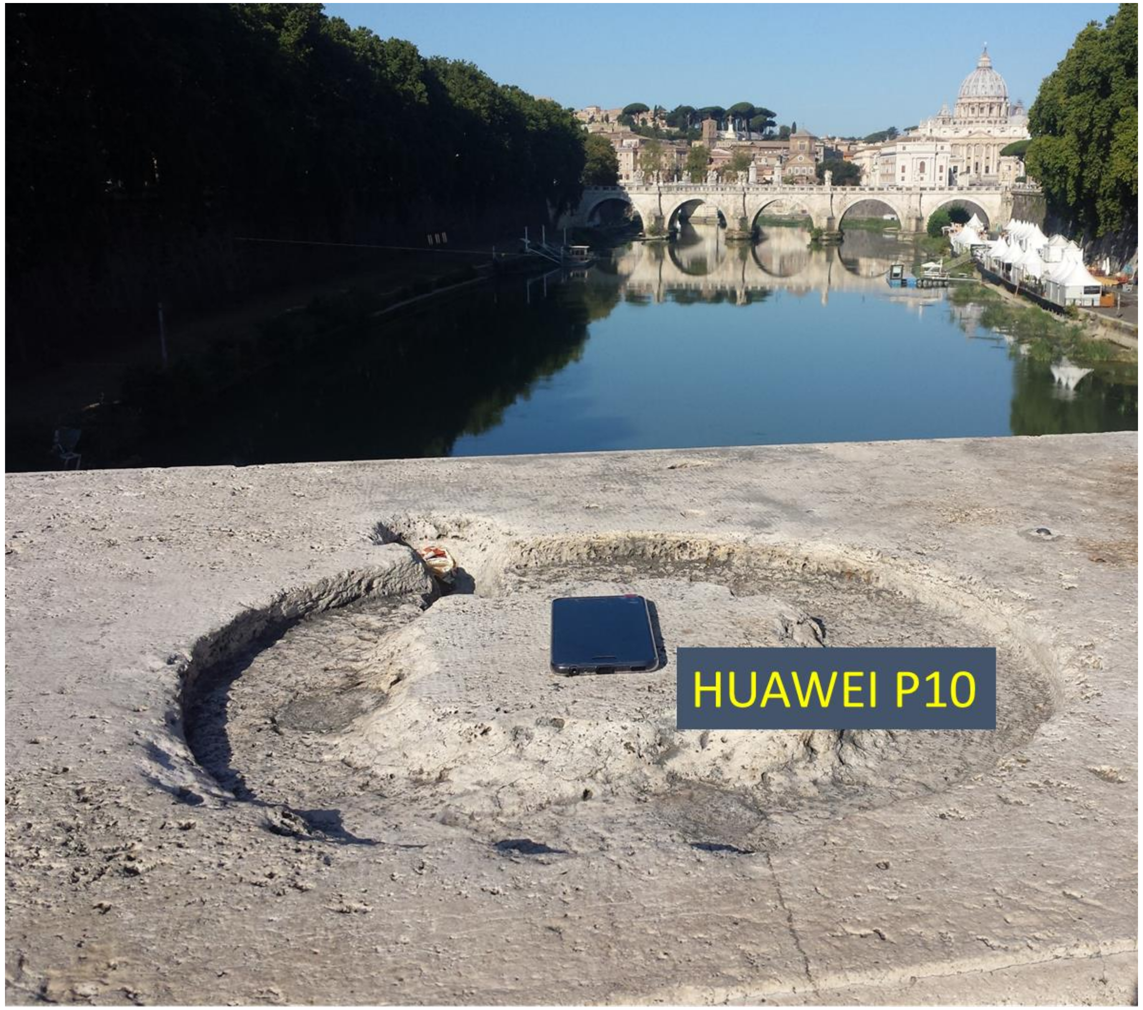
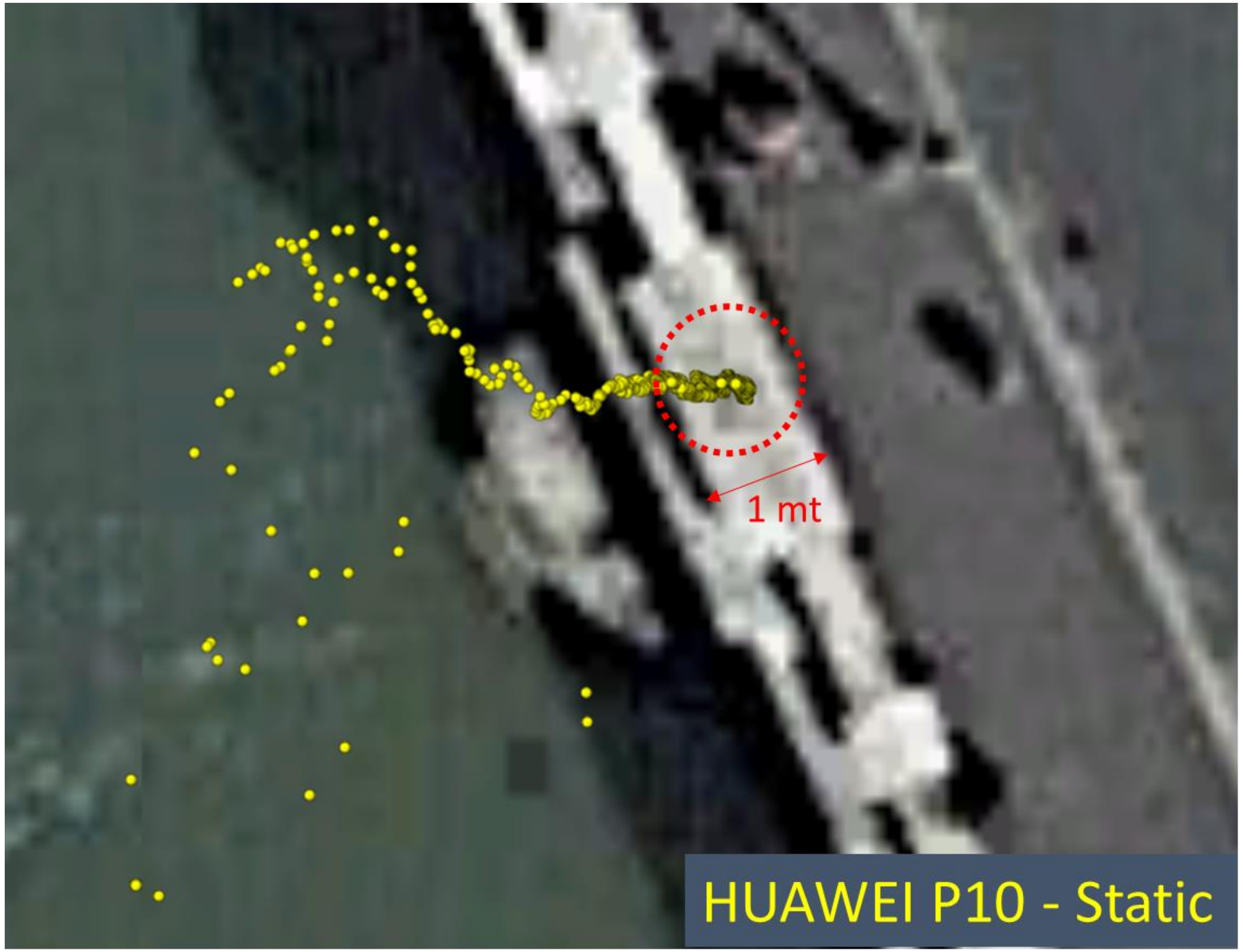
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

T-1 scenario
Huawei P10 2D accuracy in live Carrier-Phase static scenario





The Variometric Approach Idea

The approach is based on time single differences of carrier phase observations:

- continuously collected at high rate (1 Hz or higher);
- using a standalone GNSS receiver;
- using standard GNSS broadcast products (orbits and clocks) available in real-time ;
- Single and double frequency observations.

The approach is implemented in VADASE software, developed and patented by Sapienza University of Rome

Variometric Approach for Displacement Analysis Stand-Alone Engine (VADASE)

The Model

- Velocity Estimation
  - Epoch-by-Epoch LSQ velocity estimation, high-rate data
- Waveform or Displacement determination
  - Integration of estimated velocities, leads to high-rate site motion waveform and displacements

Outputs

- The direct outputs of the VADASE are velocities
  - Few centimeters displacements accuracy level in real-time (over short periods)

Since September 2015, on-board Leica Geosystems GNSS receivers

VADASE simplified functional model

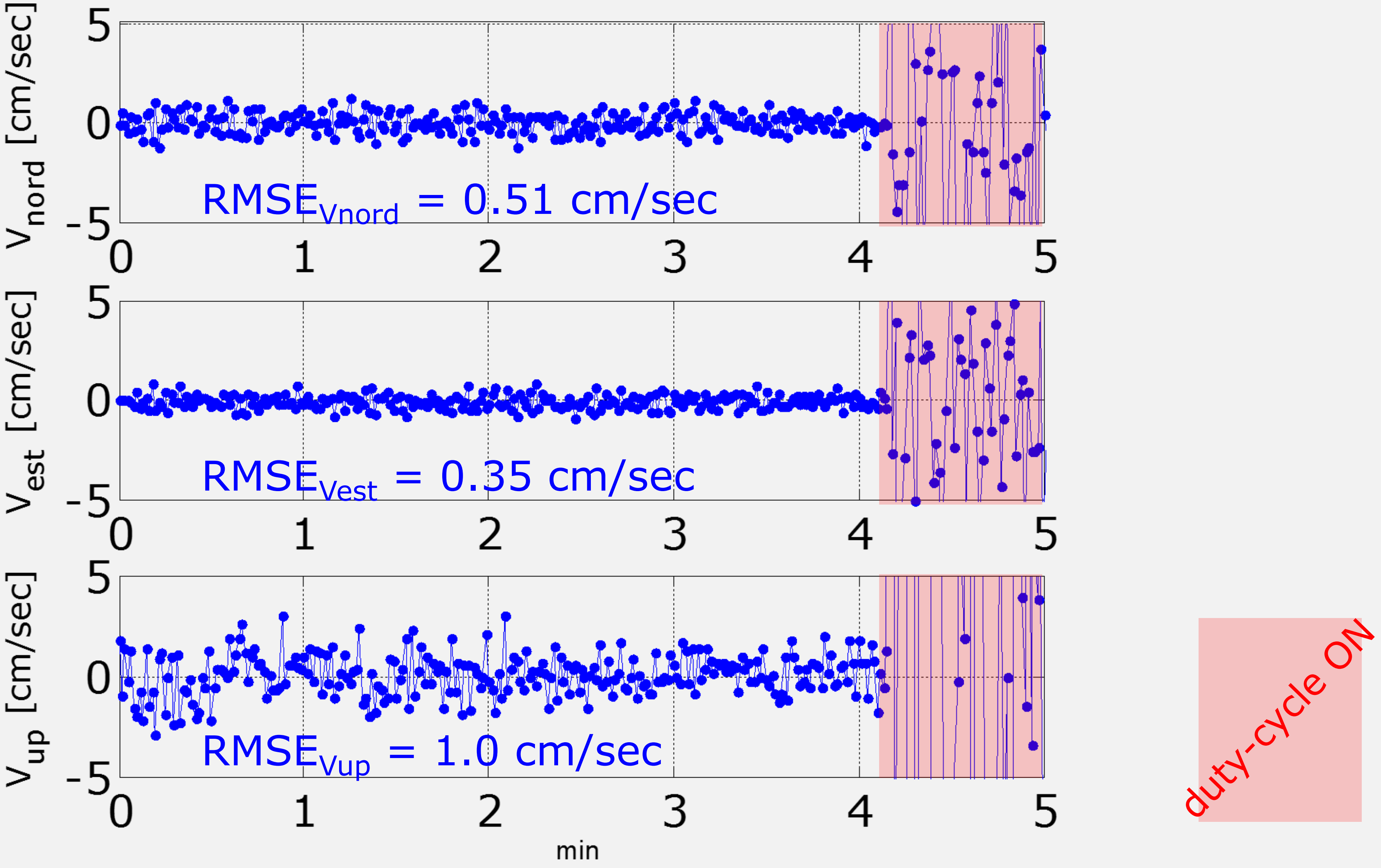
Simplified GPS L1 + Galileo E1 functional model

$$\underbrace{[\lambda\Delta\Phi_r^s]_{L1}}_{\text{time single difference observation}} = \underbrace{[\Delta\rho_r^s]_{OR} - c\Delta\delta t^s + \Delta T_r^s + \Delta I_r^s}_{\text{known term}}$$

$$+ \underbrace{(\mathbf{e}_r^s \bullet \mathbf{\Delta}\xi_r + c\Delta\delta t_r)}_{\text{terms containing the 4 unknown parameters}} + \underbrace{\epsilon_r^s}_{\text{noise}}$$

- All GPS and Galileo equations are stacked
- ΔT_r^s and ΔI_r^s variations are computed by Saastamoinen and Klobuchar models for both systems
- a single $\Delta\delta t_r$ unknown is estimated for both systems (the receiver clock variations, in short intervals, can be assumed equal)

T-1 scenario
Huawei P10 and static displacements with VADASE
Carrier Phase only – L1



T-2 scenario
Huawei P10 and pedestrian displacements with VADASE kinematic

Ref.	Device	Scenario	Type	Antenna	Duration	GNSS available	Algorithm
T-1	Huawei P10	Live	Static	Embedded	5 min	GPS+GAL	- Carrier Phase Differential (Static), Baseline~5Km - Variometric
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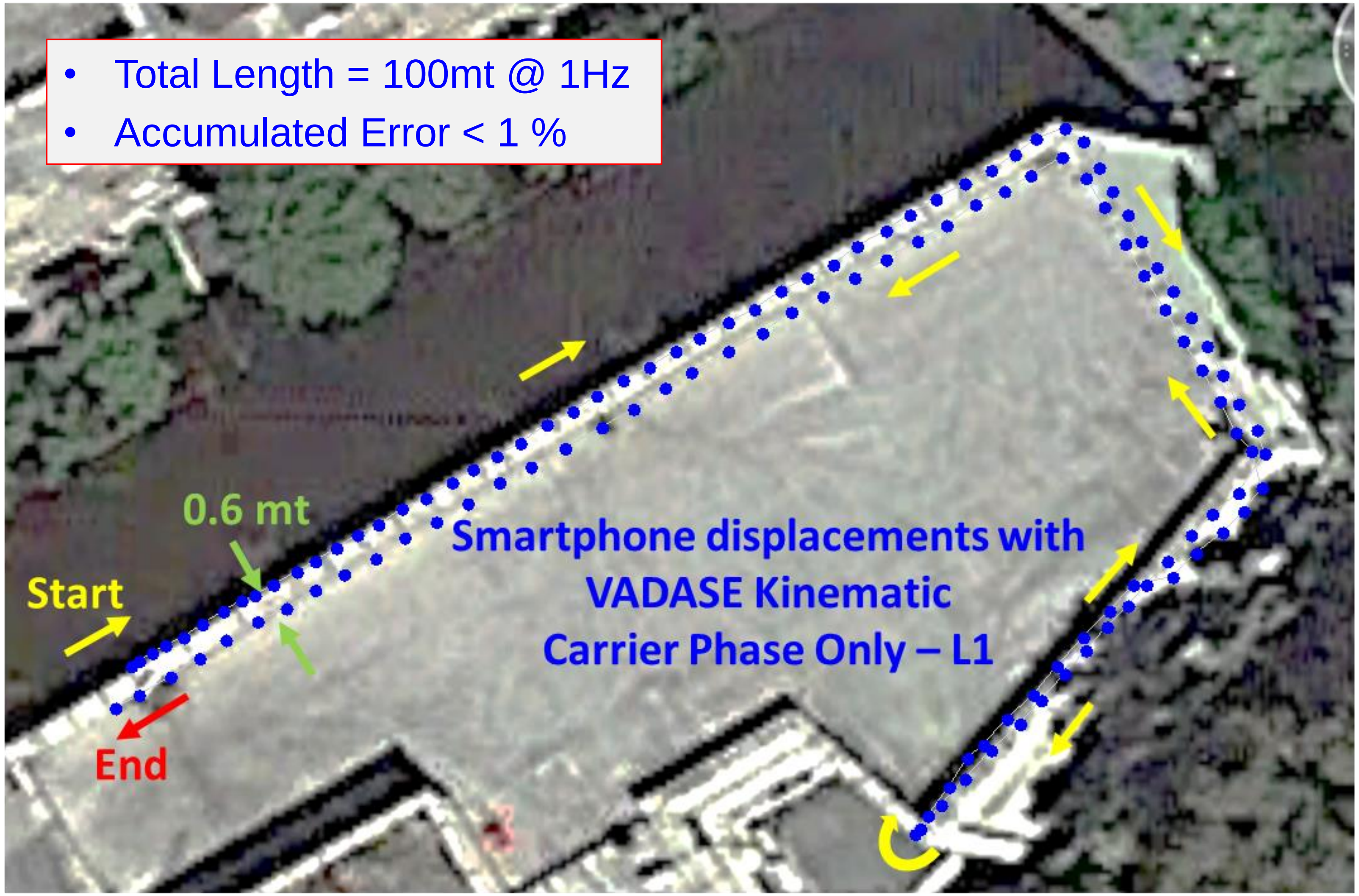
T-3			Gesture	Embedded	5 min	GPS+GAL	- Variometric
T-4			Vehicle sub-urban	Embedded	5 min 3 sessions	GPS+GAL	- Carrier Phase Differential (Kinematic), Baseline~4Km - Variometric
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

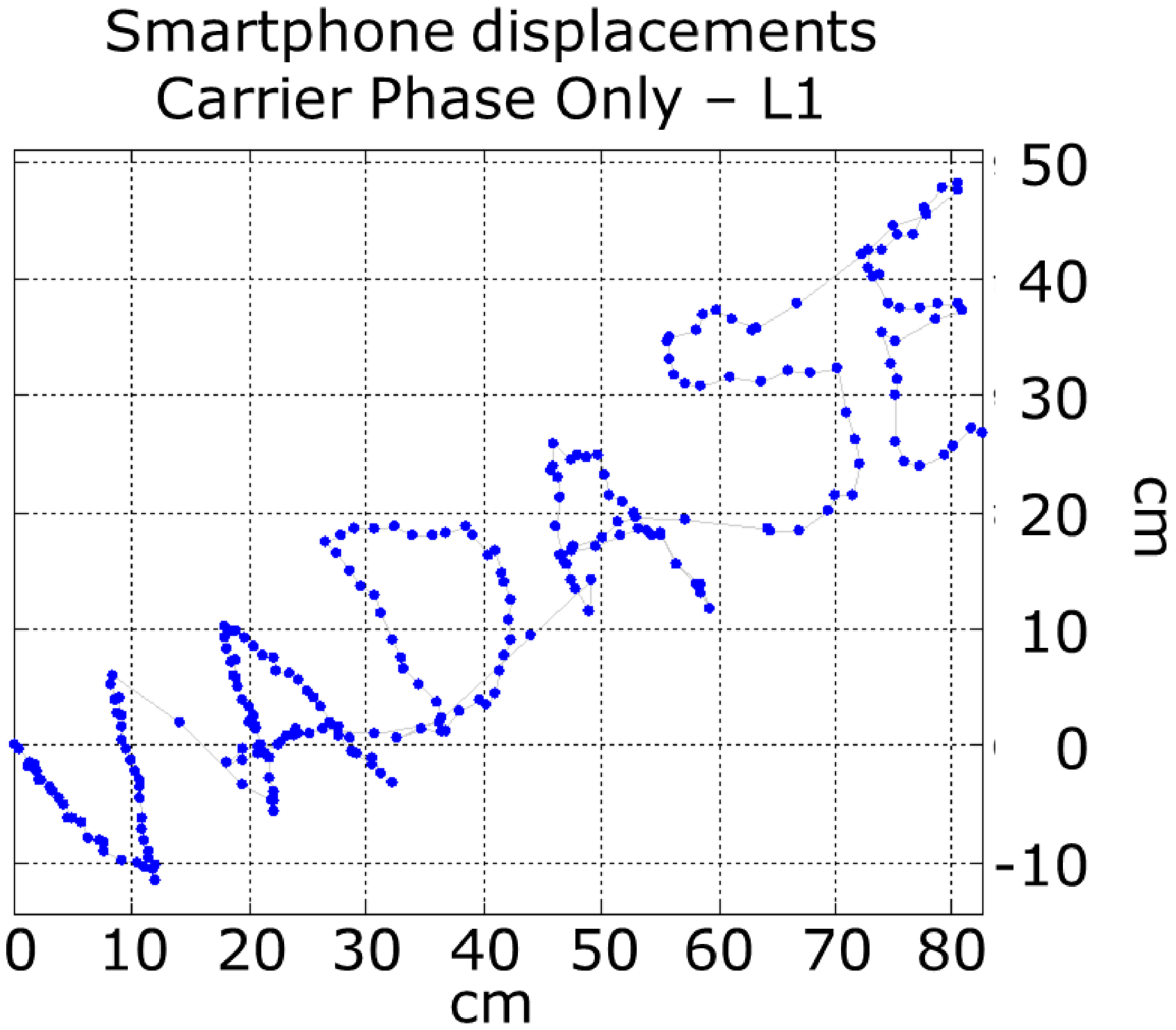
T-2 scenario
Huawei P10 and pedestrian displacements with VADASE kinematic Carrier Phase only – L1



T-3 scenario
Huawei P10 and gestures with VADASE kinematic

Ref.	Device	Scenario	Type	Antenna	Duration	GNSS available	Algorithm
T-1	Huawei P10	Live	Static	Embedded	5 min	GPS+GAL	- Carrier Phase Differential (Static), Baseline~5Km - Variometric
T-2			Pedestrian	Embedded	5 min	GPS+GAL	- Variometric
T-3			Gesture	Embedded	5 min	GPS+GAL	- Variometric
T-4			Vehicle sub-urban	Embedded	5 min 3 sessions	GPS+GAL	- Carrier Phase Differential (Kinematic), Baseline~4Km - Variometric
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

T-3 scenario
Huawei P10 and gestures with VADASE kinematic
Carrier Phase only – L1



T-4 scenario
Huawei P10 in live vehicle sub-urban scenario

Ref.	Device	Scenario	Type	Antenna	Duration	GNSS available	Algorithm
T-1	Huawei P10	Live	Static	Embedded	5 min	GPS+GAL	- Carrier Phase Differential (Static), Baseline~5Km - Variometric
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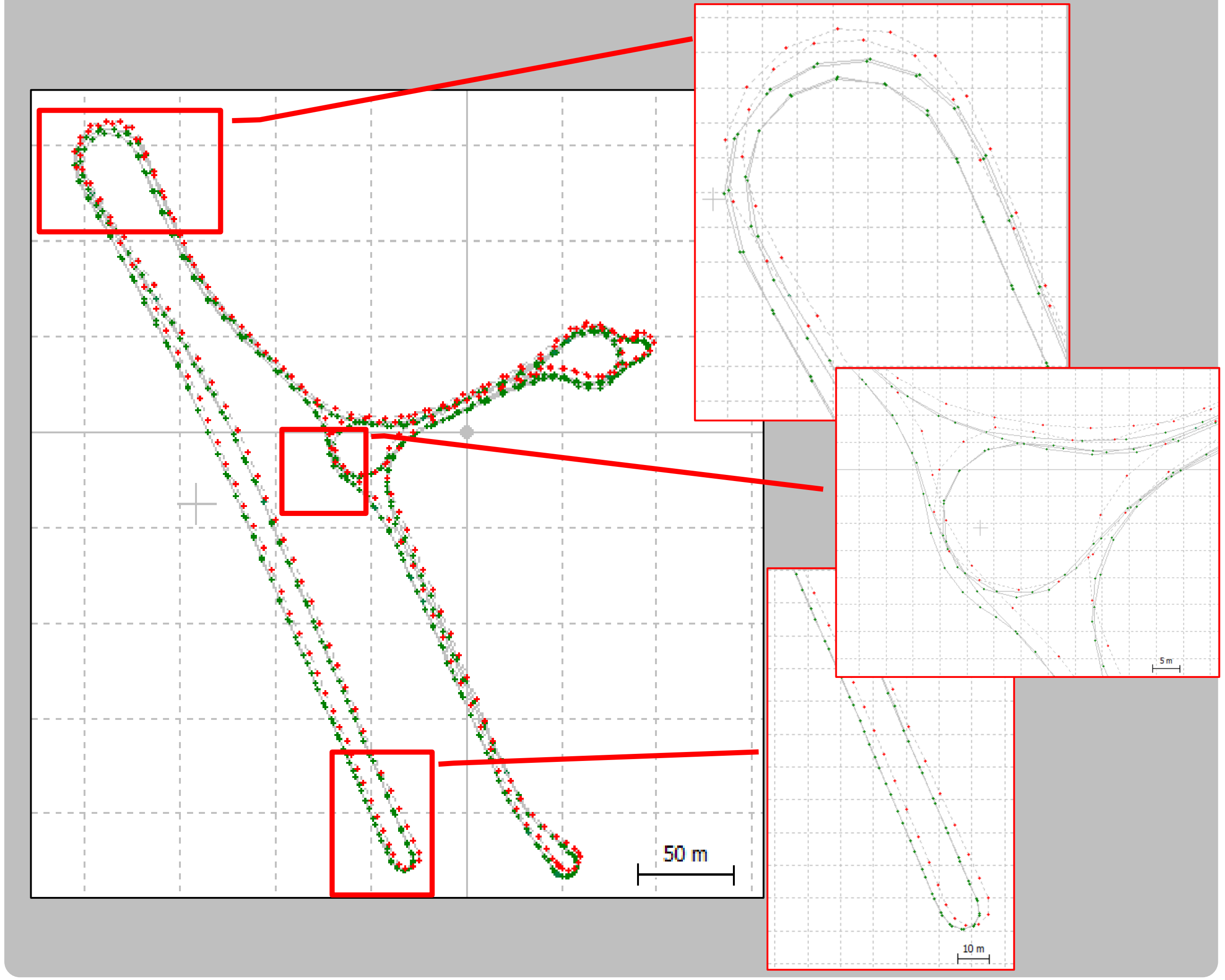
T-3			Gesture	Embedded	5 min	GPS+GAL	- Variometric
T-4			Vehicle sub-urban	Embedded	5 min 3 sessions	GPS+GAL	- Carrier Phase Differential (Kinematic), Baseline~4Km - Variometric
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

T-4 scenario
Huawei P10 in live vehicle sub-urban scenario

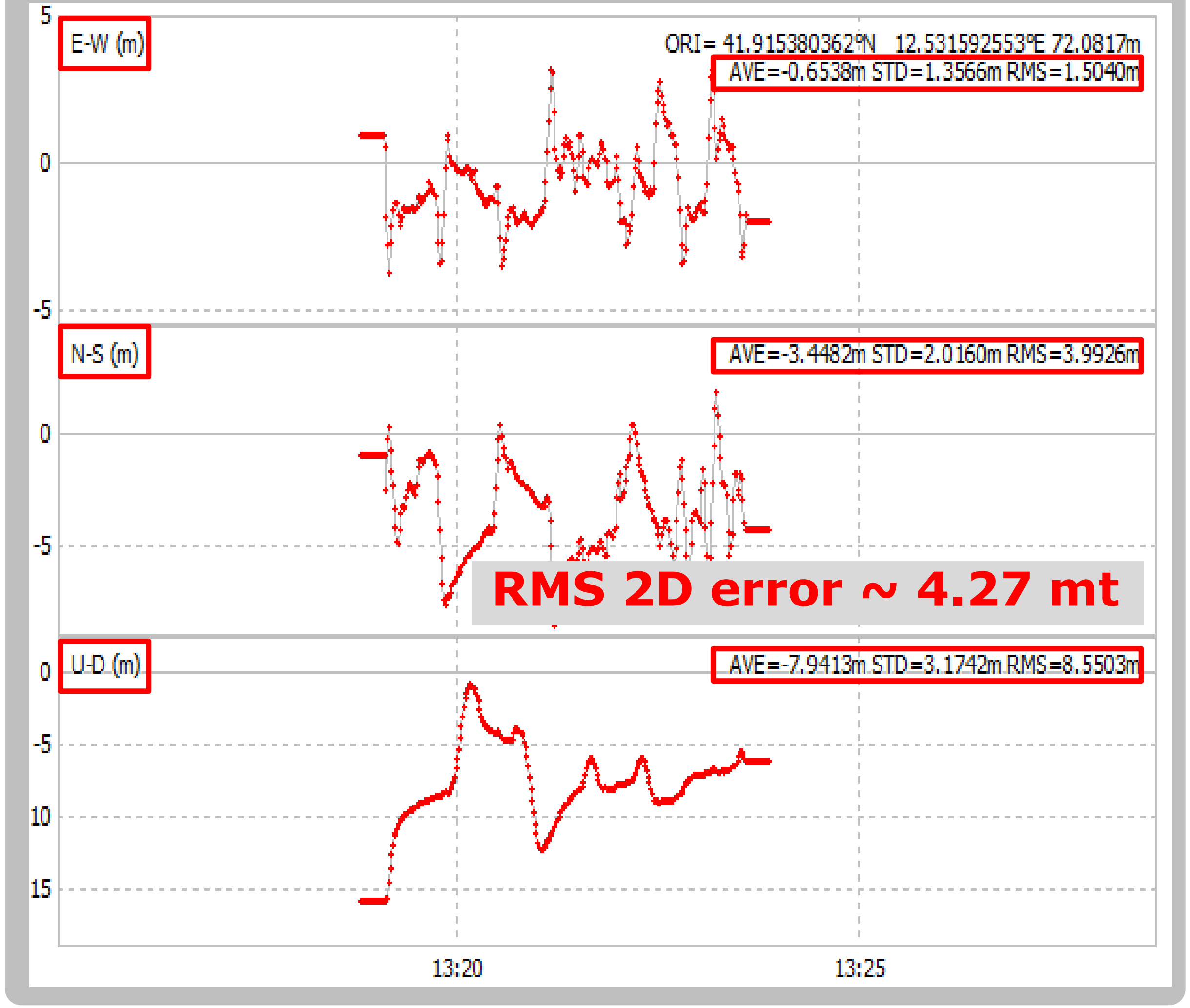
T-4 scenario
Huawei P10 in live vehicle sub-urban scenario
Carrier-phase Kinematic – L1

T-4 scenario
Huawei P10 in live vehicle sub-urban scenario
LEICA vs Smartphone internal solution (from NMEA)

Ground Track

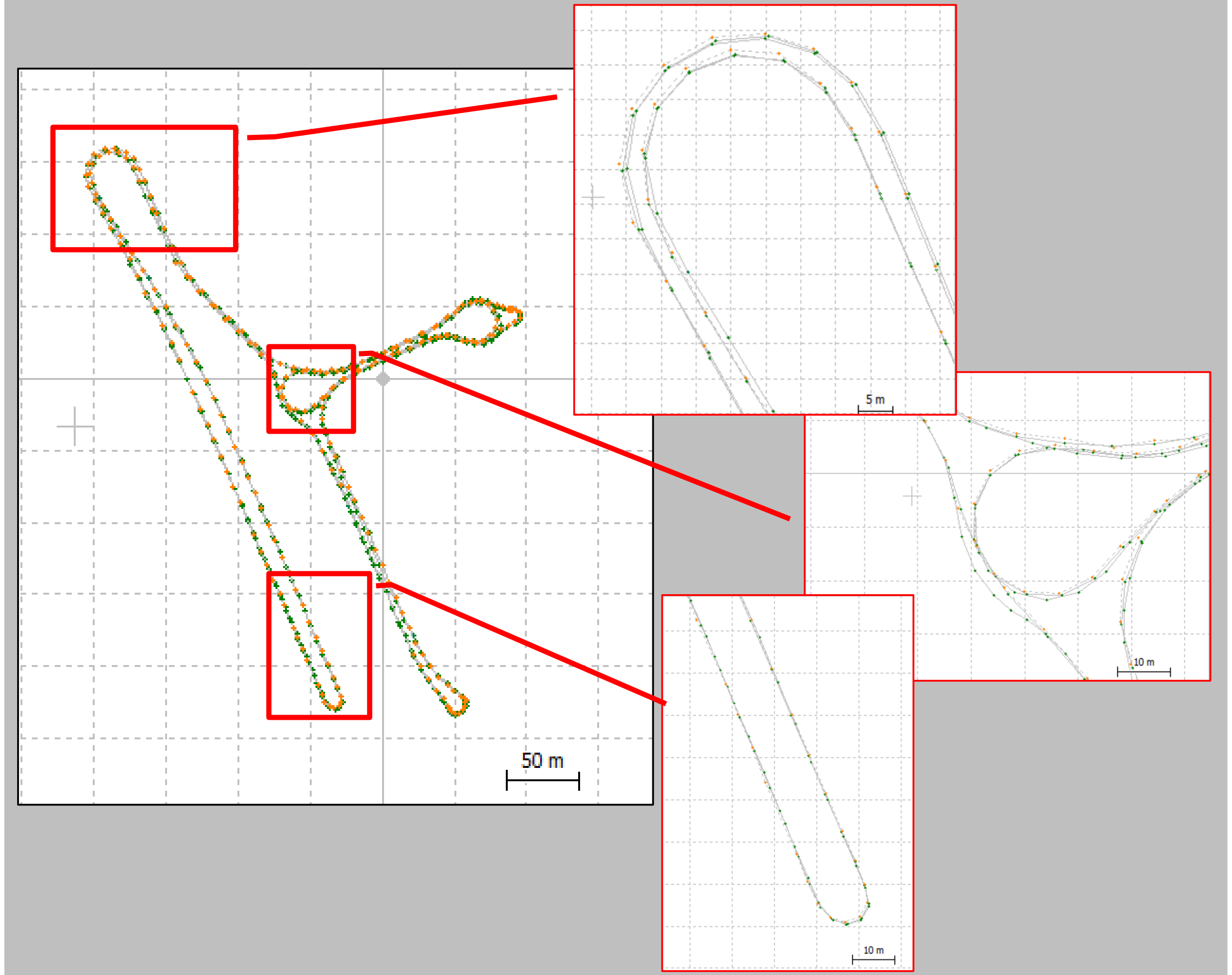


Performance (includes the fixed distance btw antennas)

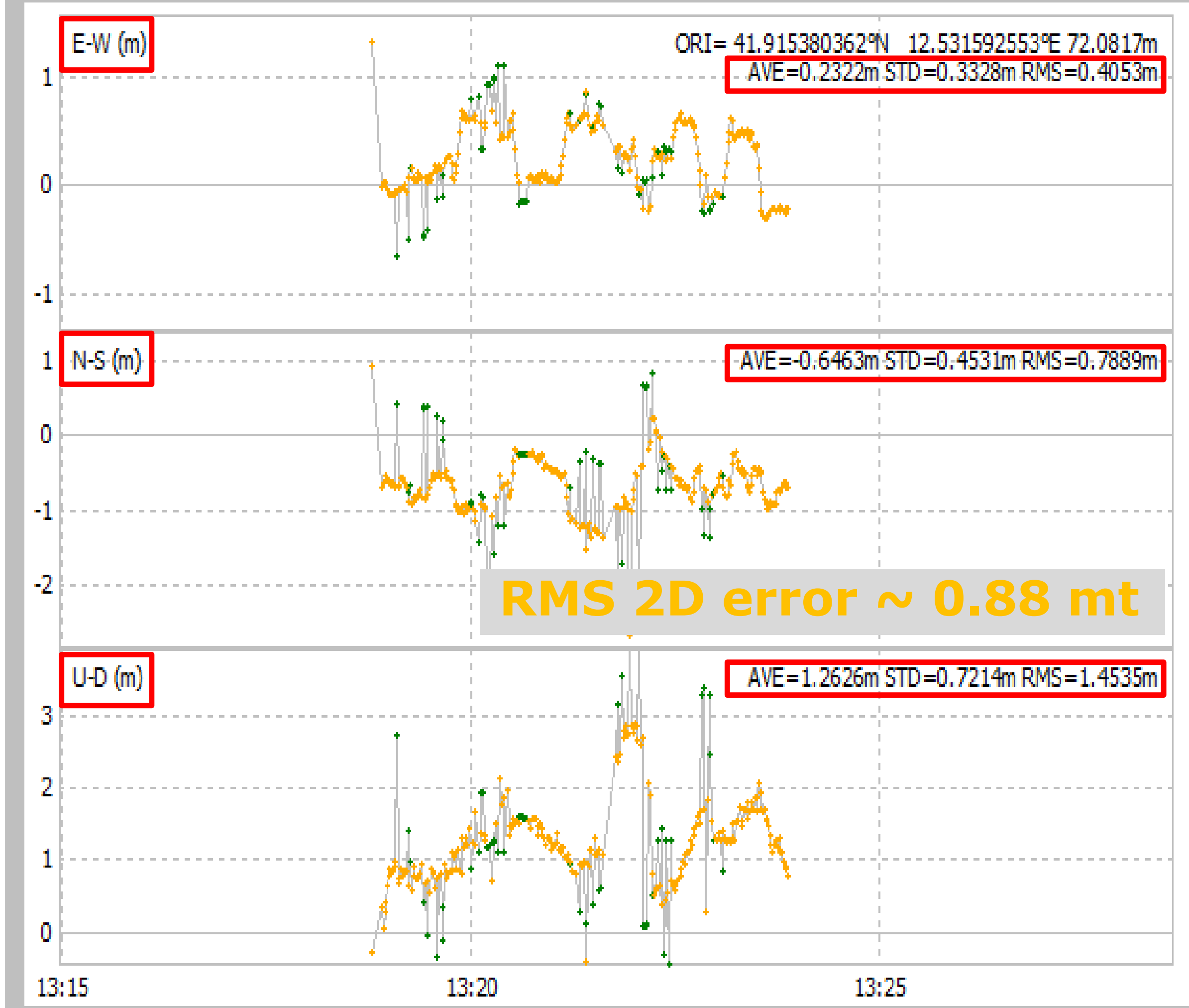


T-4 scenario
Huawei P10 in live vehicle sub-urban scenario
LEICA vs Smartphone Carrier-phase Kinematic – L1

Ground Track



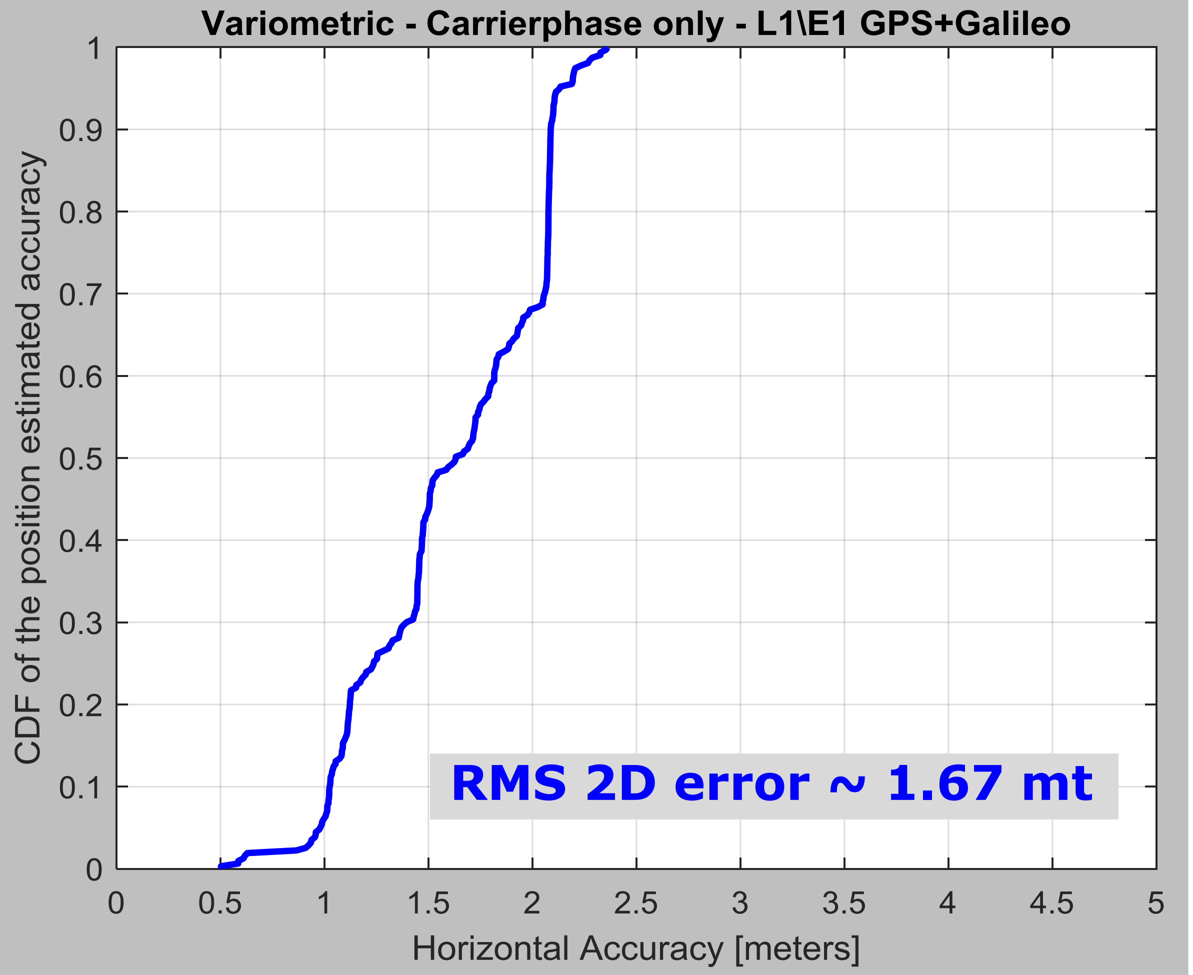
Performance (includes the fixed distance btw antennas)



T-4 scenario
Huawei P10 in live vehicle sub-urban scenario
LEICA vs VADASE-carrier-phase only–GPS (L1)

Ground Track

Performance (includes the fixed distance btw antennas)



T-5 scenario
Samsung S8 in live aircraft scenario

Ref.	Device	Scenario	Type	Antenna	Duration	GNSS available	Algorithm
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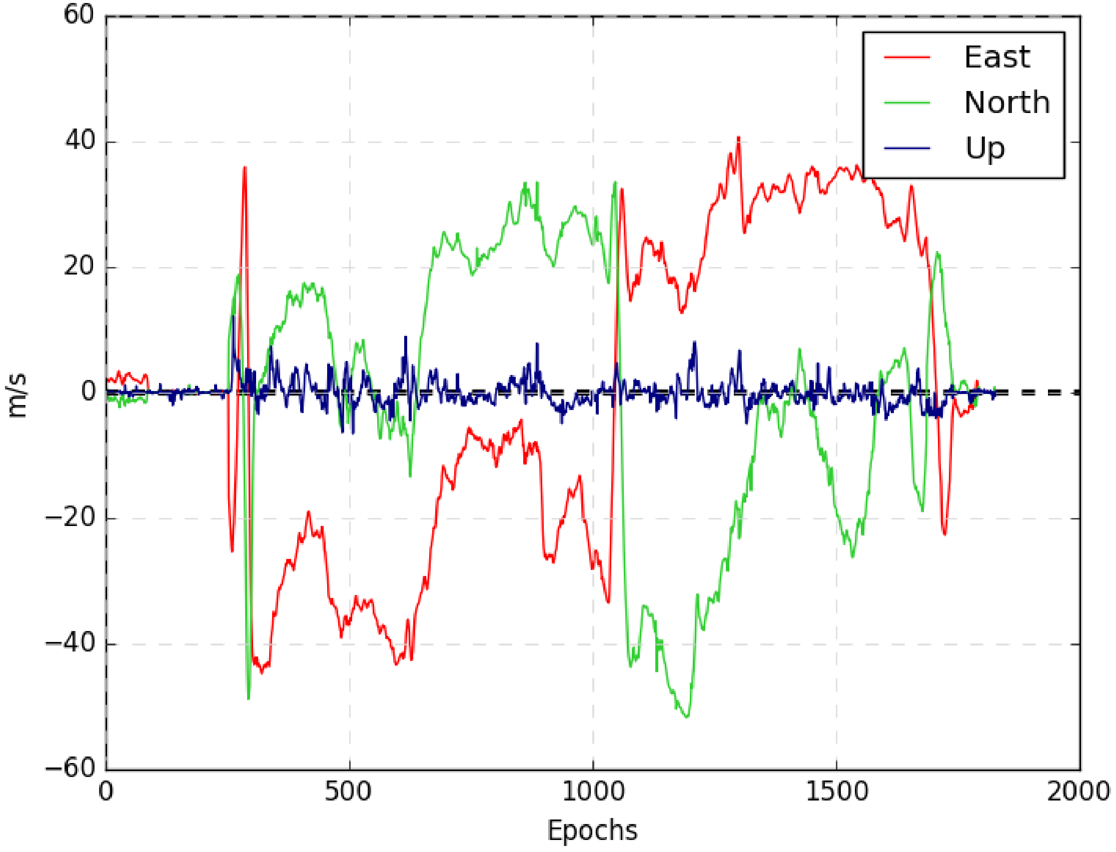
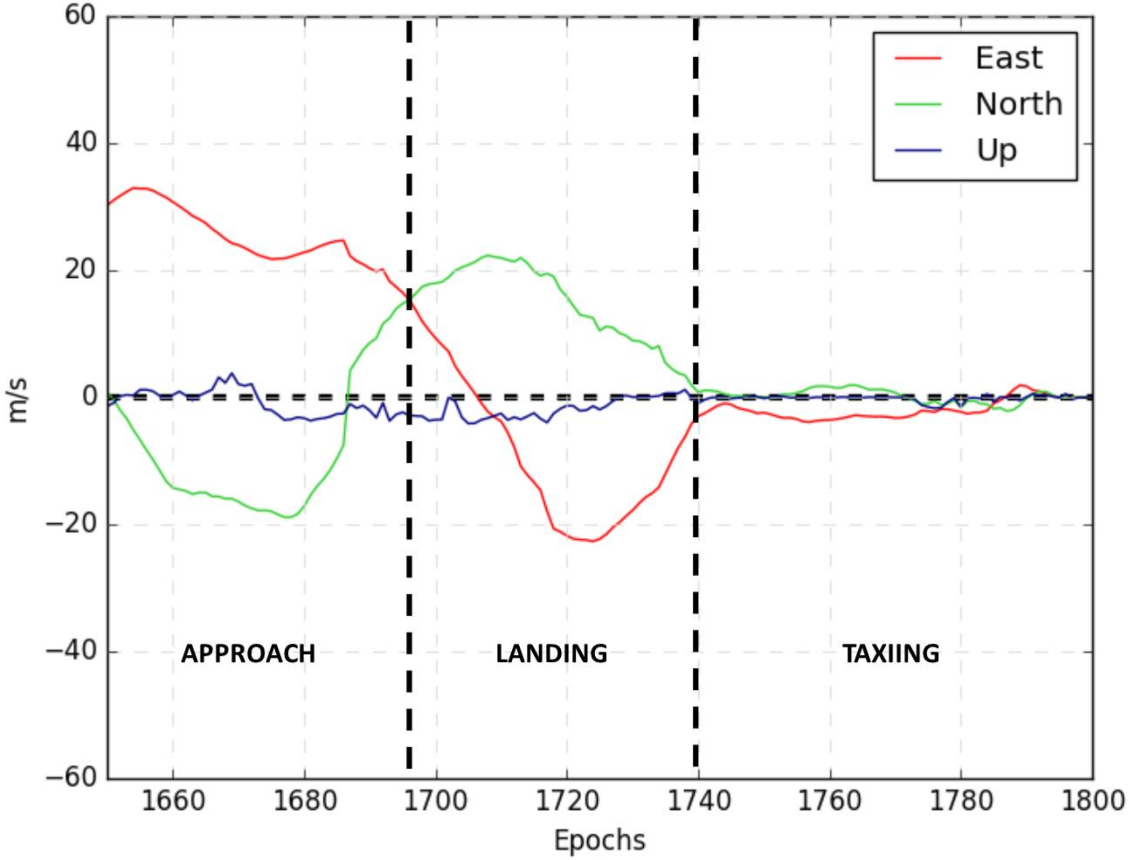
T-5	Samsung S8		Aircraft	Embedded	1 hr	GPS+GAL	- Variometric

T-5 scenario
Samsung S8 in live **aircraft** scenario

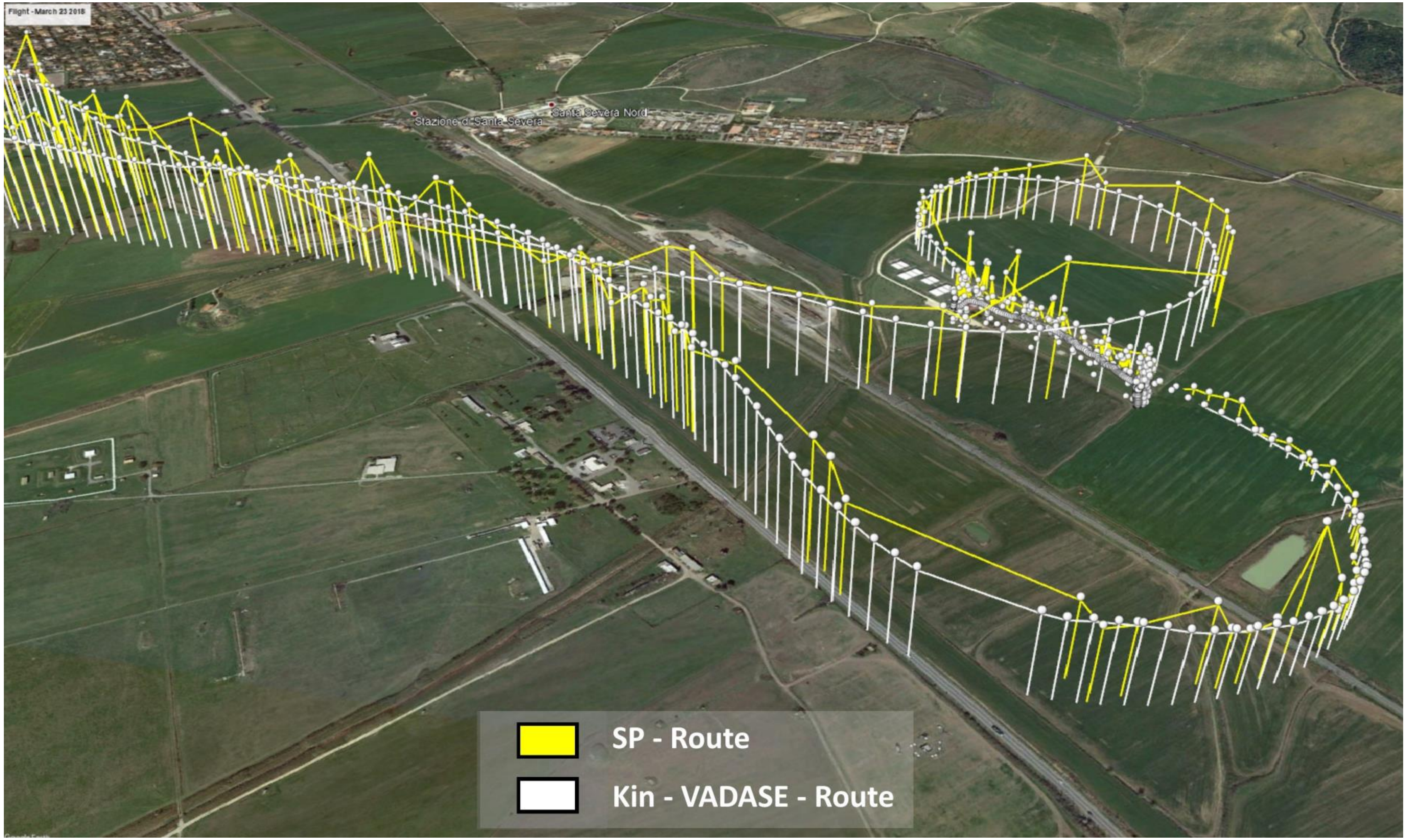
Experiment developed during M.Sc Thesis by Eng. E. Fornaciari Defended on 29 May 2018

T-5 scenario
Samsung S8 in live aircraft scenario

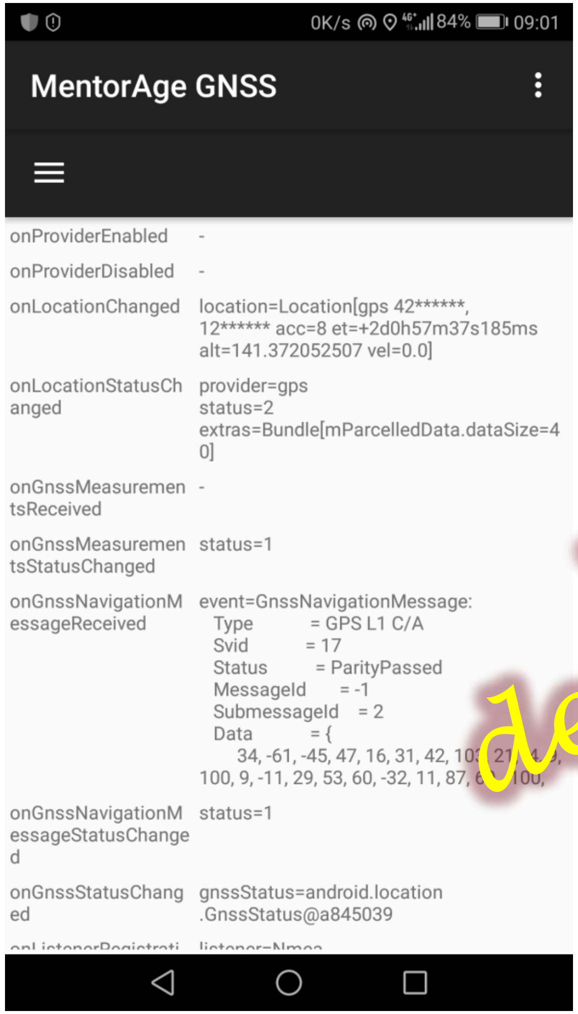




T-5 scenario
Samsung S8 in live aircraft scenario



Snapshot of the app MentorAge GNSS
RINEX acquisition + Variometric approach live implementation



Under development

Conclusions

- The preliminary results with the Variometric approach are very promising.
- Reliable solutions can be obtained when the User can:
  - Select the type of GNSS;
  - Disable/enable the duty-cycle of the power;
  - Access to data estimated with a good clock.
- The use of raw measurements from smartphone opens the way to new interesting applications:
  - IOT and LBS;
  - Two ore more smartphones connected together;
  - Gesture and images or video correlated (Virtual or Augmented Reality).


Greetings from Rome !
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augusto.mazzoni@uniroma1.it