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GNSS-Messungen von Smartphones:

Herausforderungen, Verarbeitung und Potential

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GARFIELD

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- Einleitung
- Herausforderungen
- Verarbeitung
- Potential

adapted from Yang et al. (2023)

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first Android smartphone

2008

Xiaomi Mi 8

first dual-frequency (DF) smartphone

2018

time

1999

first commercially-available phone with GPS

2016

access to GNSS measurements on Android

Developers

2024+

wide-spread support of multiple constellations and two GNSS frequencies

- Einleitung
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Access

Android devices significantly differ in their capabilities regarding raw GNSS measurements

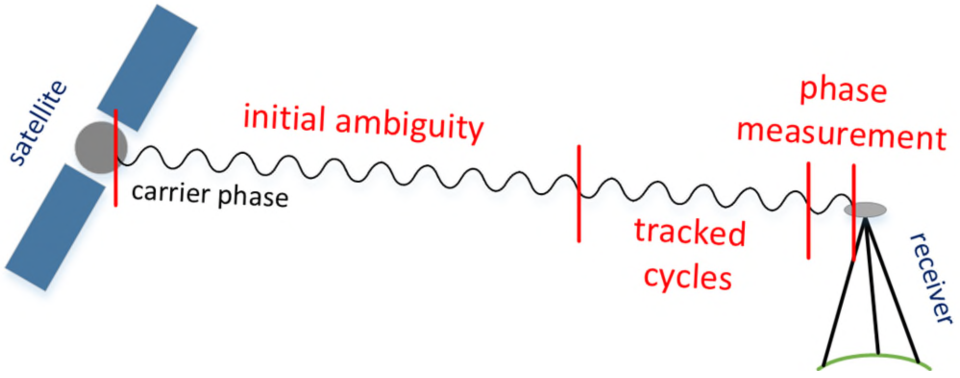
Possible limitations:

- No phase measurement
- Market-specific restrictions
- Really dual-frequency?!

GPSTest Database
(Barbeau, 2021)

Phase observation

- Not accessible on many smartphones
- Essential to achieve $\ll 1\,\mathrm{m}$
- Tricky to use:
  - Ambiguity jumps (e.g., duty cycling)
  - Cycle slips
  - Inconsistencies of logger applications



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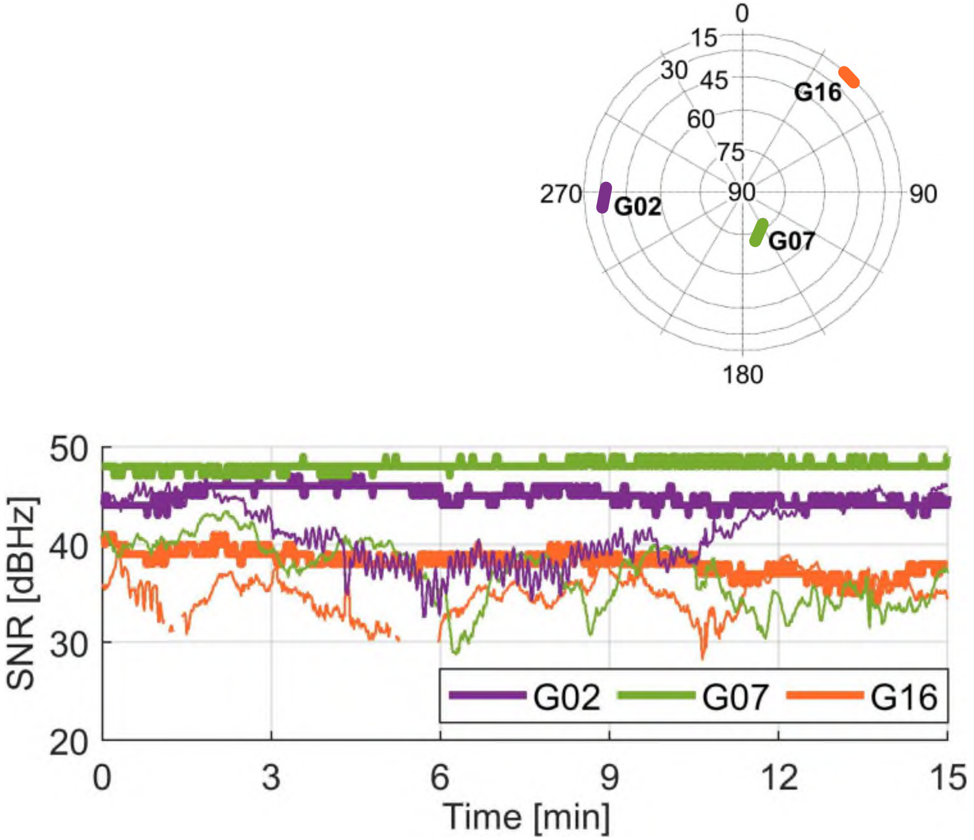
Carrier-to-Noise Density

- Around 10 dBHz less than for geodetic equipment
- More variable
- The lower the C/N0, the less reliable the corresponding measurements

→ C/N0 threshold (e.g., 20 dBHz)



Trimble Spectra Sp80 vs. Google Pixel 5

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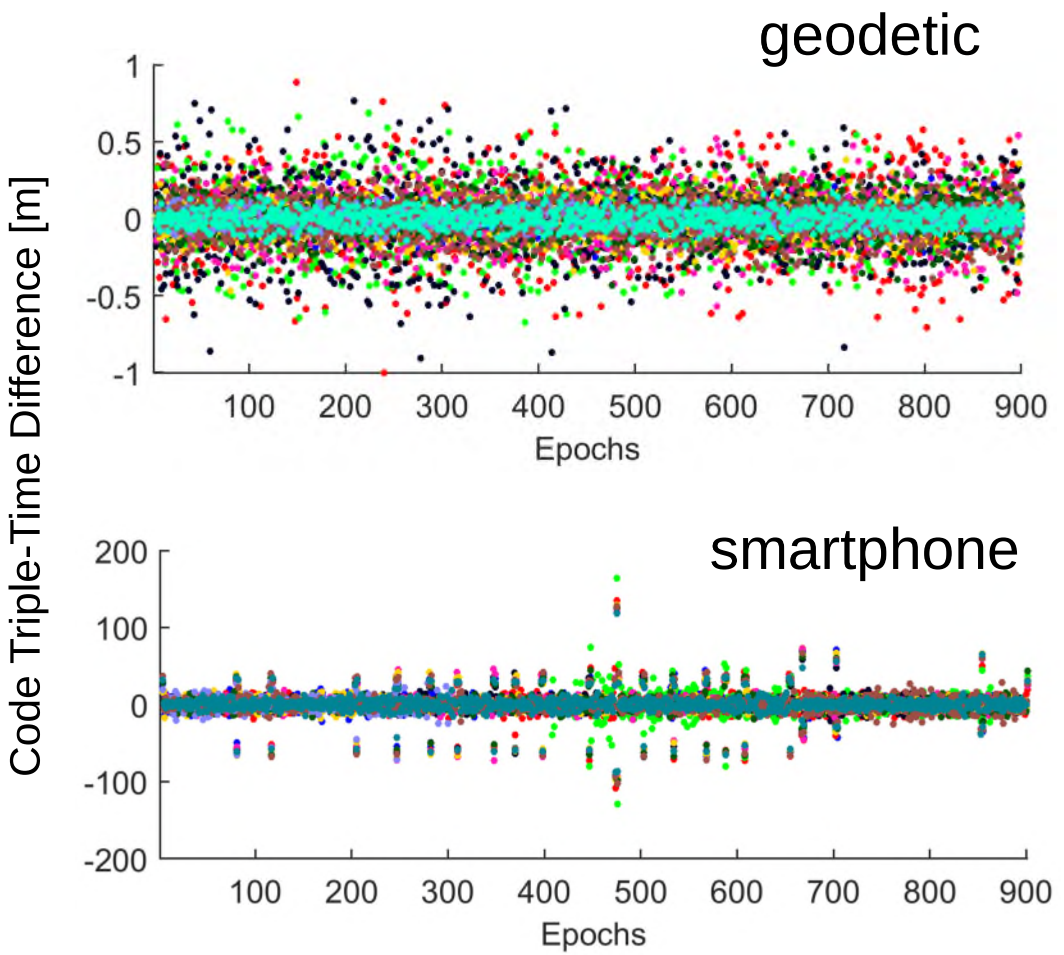
Observation quality

- Anomalies much more pronounced
- Outliers are common (e.g., Multipath)
- Factor 10-100 worse



Triple-Time Difference

- Difference measurements of last 4 epochs
- In theory, only observation noise remains[1]
- Example calculation:

$$C_{TD} = (C_i - C_{i-1}) - (C_{i-2} - C_{i-3})$$

C … code measurement

i … epoch

C_{TD} … triple-time differenced code observations

[1] static receiver and high-rate observations

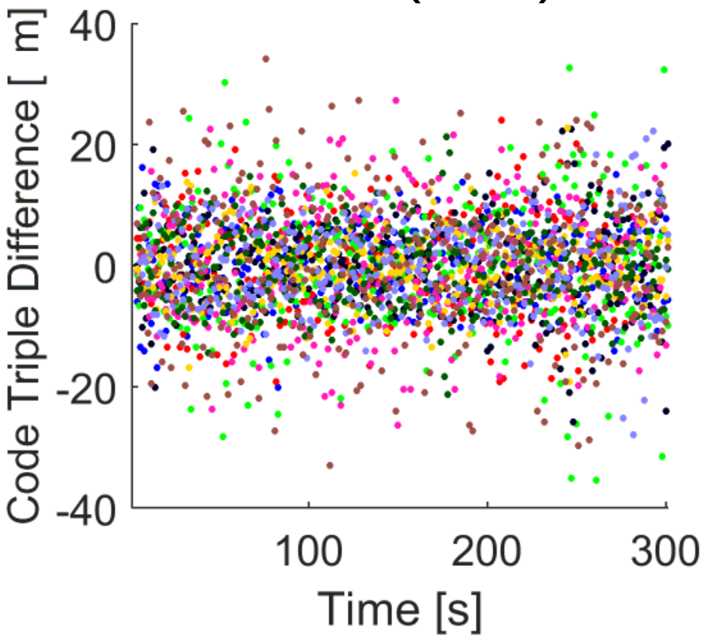
Google Pixel 7 Pro

- Released: October 6, 2022
- GPS, GLONASS, Galileo, BeiDou
- Dual-frequency (L1 & L5)
- Provides carrier-phase observations

Observation Noise

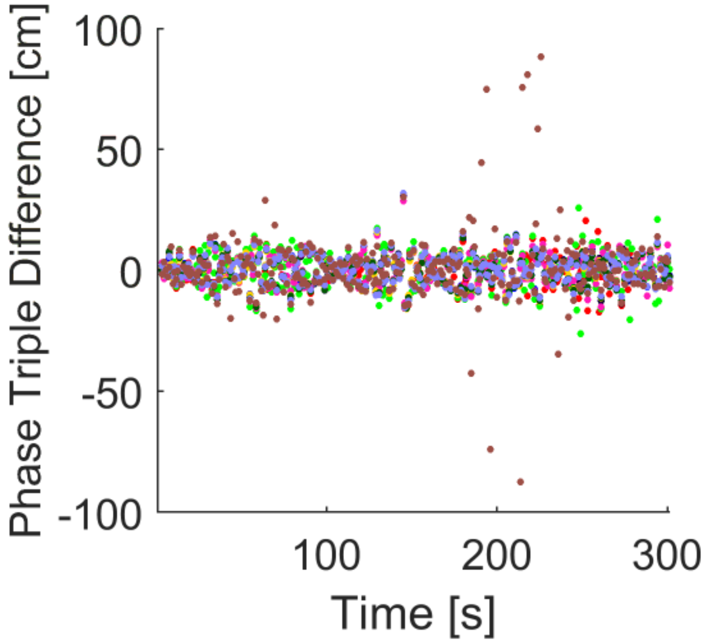
Google Pixel 7, triple-time difference

Code (C1C)



std = 8.45 m

Phase (L1C)



std = 12.9 cm

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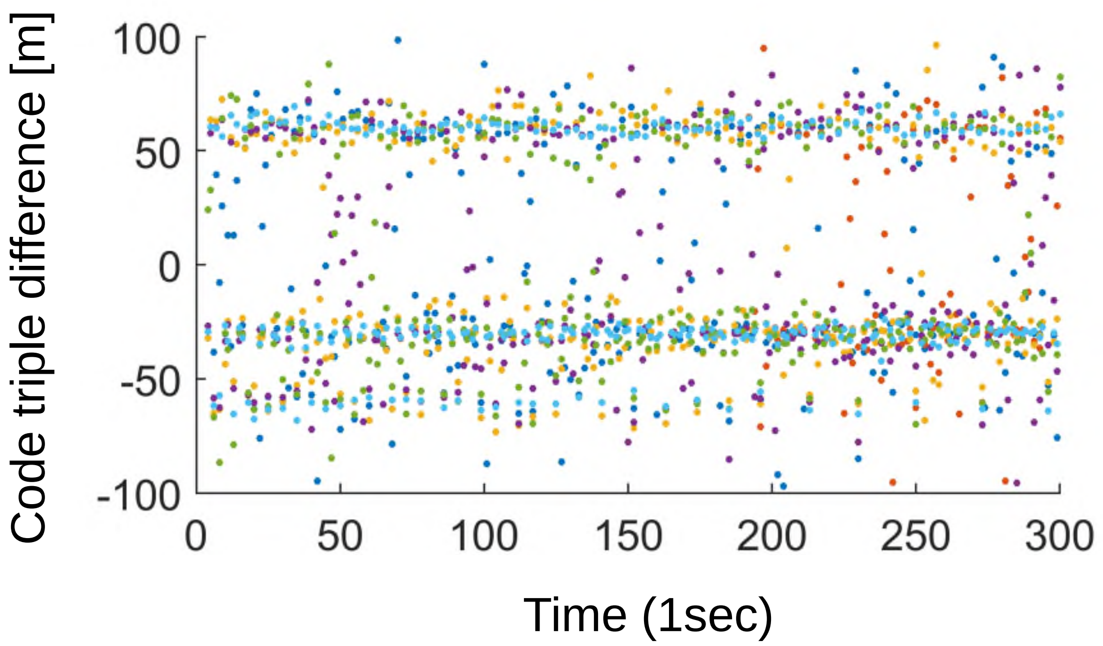
Observation Generation

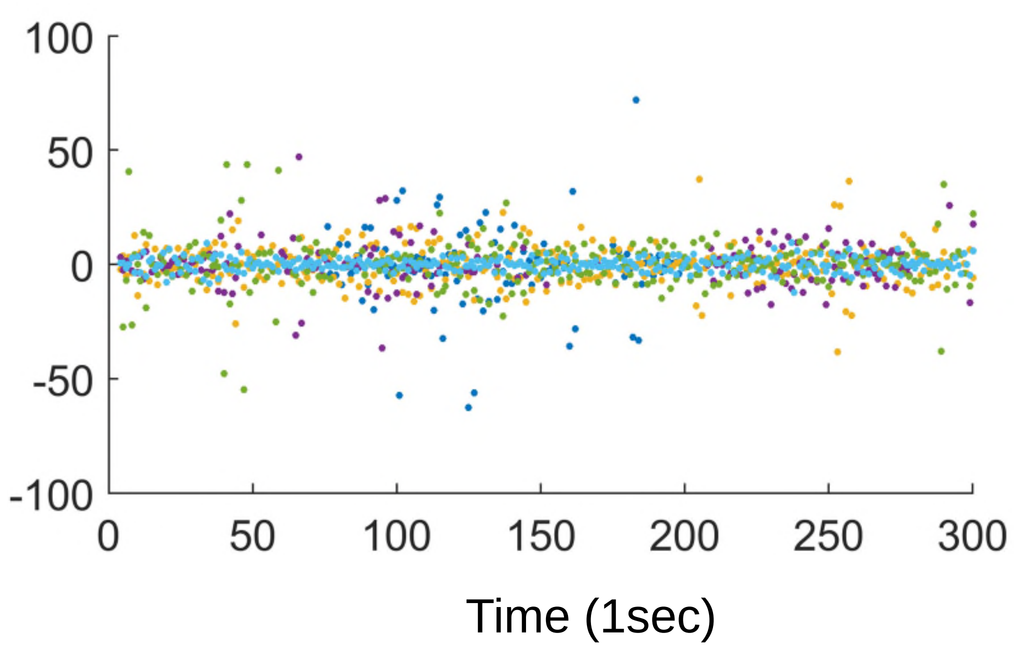
- Android API provides GNSS measurements as time-stamps
- Generation of phase and Doppler observation is simple
- Pseudorange generation is tricky

Generated Pseudorange

Google GnssLogger (RINEX)

raPPPid





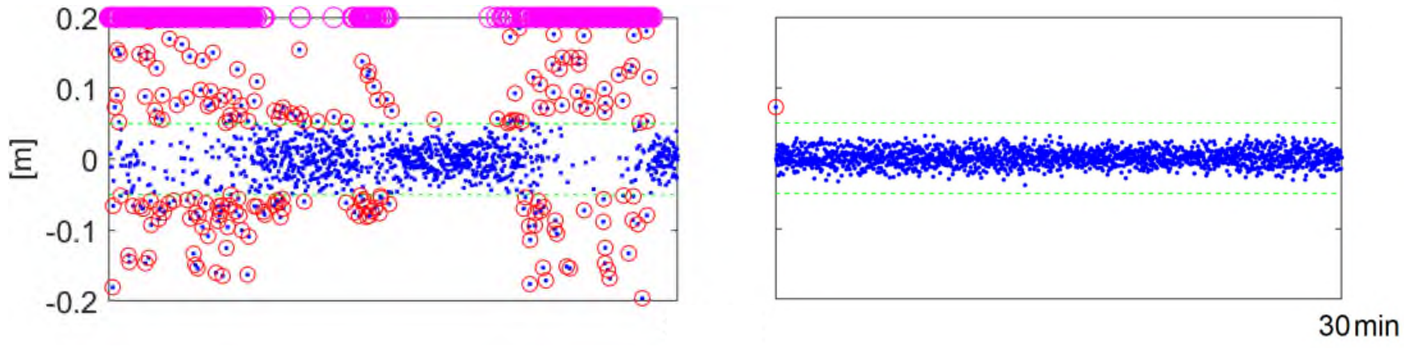
more on this topic:
(Zangenehnejad et al., 2023)

Cycle-Slip Detection

$L_{old} + dt\sqrt{D_{now}D_{old}} < 0.8\ cy$ … with Doppler-Shift

dL_1 - $dL_5 < 0.05\ cm$ … with phase difference

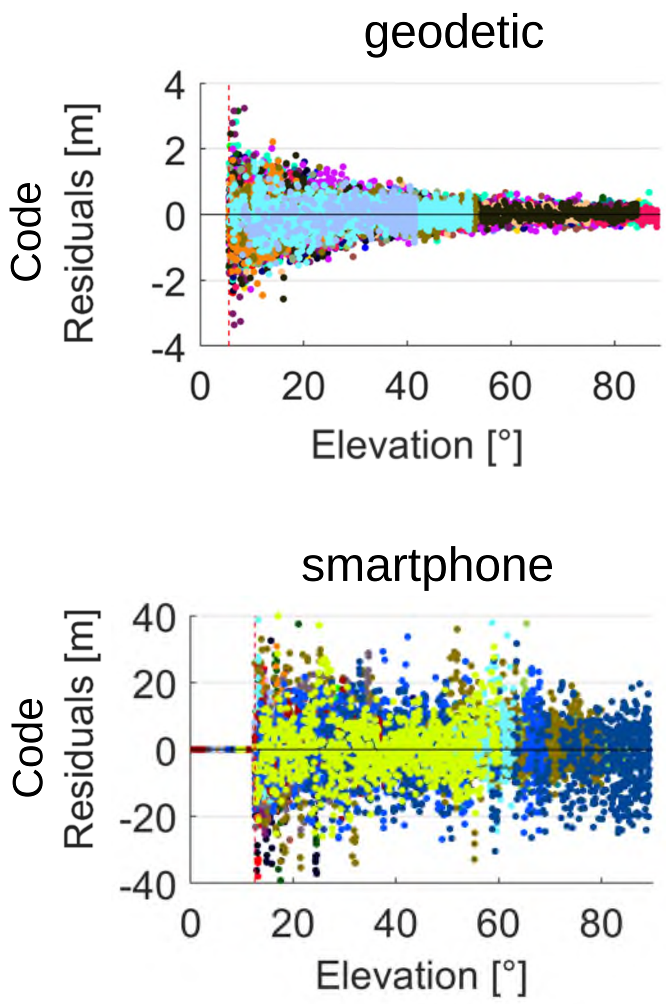
dL_{E1} - dL_{E5a}



E02 April 4, 2023 E07

Observation weighting

- Essential for parameter estimation
- Usually: elevation-dependent weighting
- Not suitable for smartphones



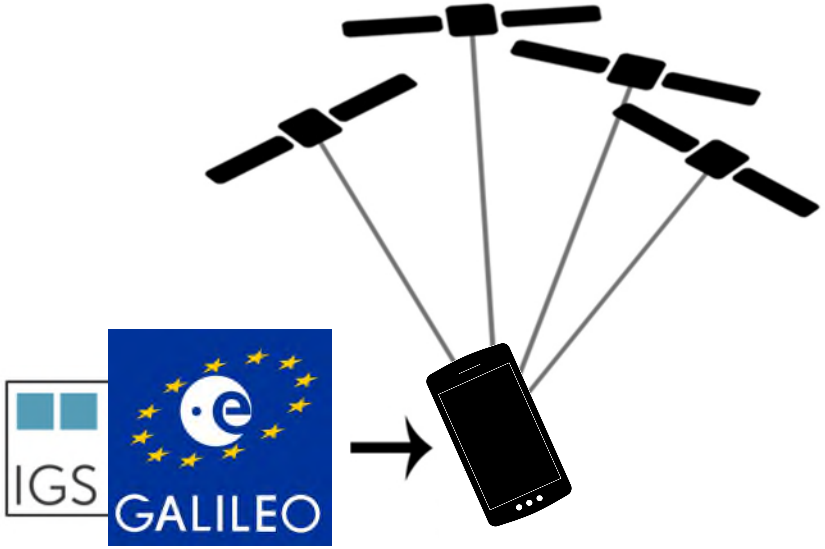
Precise Point Positioning

PPP relies on:

- Precise satellite products:
  orbits, clocks and biases
- Complex models and algorithms

Geodetic accuracy: cm, or even mm

Major drawback: convergence time



HAS

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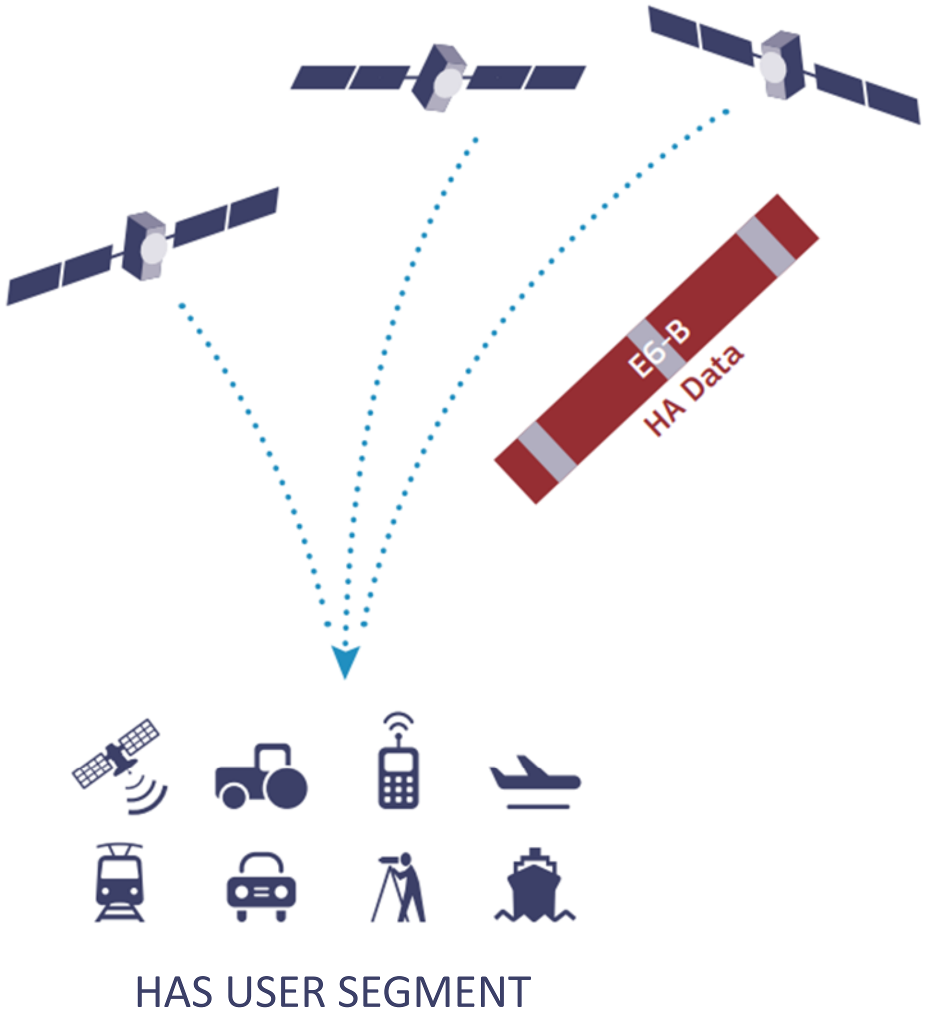
Galileo High Accuracy Service

- Real-time corrections for GPS & Galileo
- Free-of-charge
- Dissemination over
  - Signal in space (E6-B)
  - The Internet (since January 24, 2023)



Observation Model

$$P_1 = \rho + c(dt_r + \delta t^g) + dTrop^{wet} + dIono_1 + \varepsilon$$

$$L_1 = \rho + c(dt_r + \delta t^g) + dTrop^{wet} - dIono_1 + \lambda_1 N_1 + \varepsilon$$

$$dIono_{pseudo} = dIono_1 + \varepsilon$$

- Uncombined model with ionospheric constraint
- Maintains raw observation noise
- Flexibel, handles any number of frequencies

Observation Model

$$P_1 = \rho + c(dt_r + \delta t^g) + dTrop^{wet} + dIono_1 + \varepsilon$$

$$L_1 = \rho + c(dt_r + \delta t^g) + dTrop^{wet} - dIono_1 + \lambda_1 N_1 + \varepsilon$$

$$dIono_{pseudo} = dIono_1 + \varepsilon$$

Dual-frequency smartphone

$$P_2 = \rho + c(dt_r + \delta t^g) - DCB_{12} + dTrop^{wet} + \frac{f_1^2}{f_2^2} dIono_2 + \varepsilon$$

$$L_2 = \rho + c(dt_r + \delta t^g) - DCB_{12} + dTrop^{wet} - \frac{f_1^2}{f_2^2} dIono_2 + \lambda_2 N_2 + \varepsilon$$

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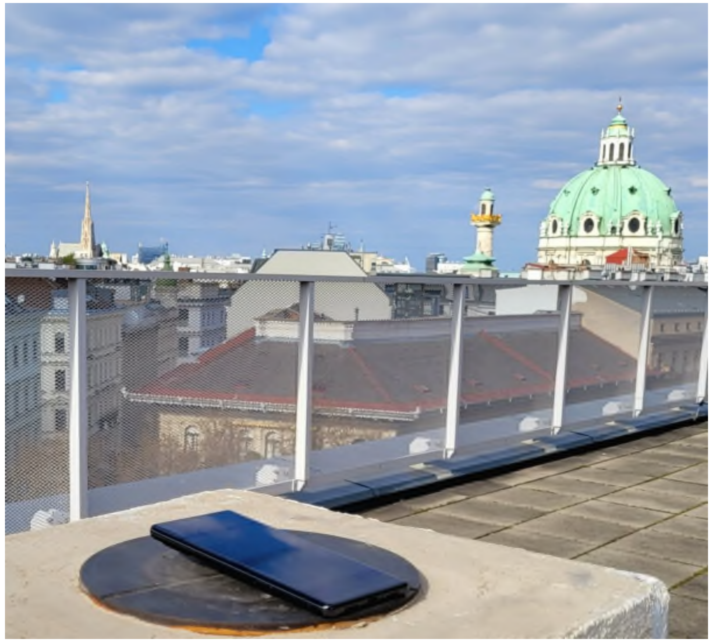
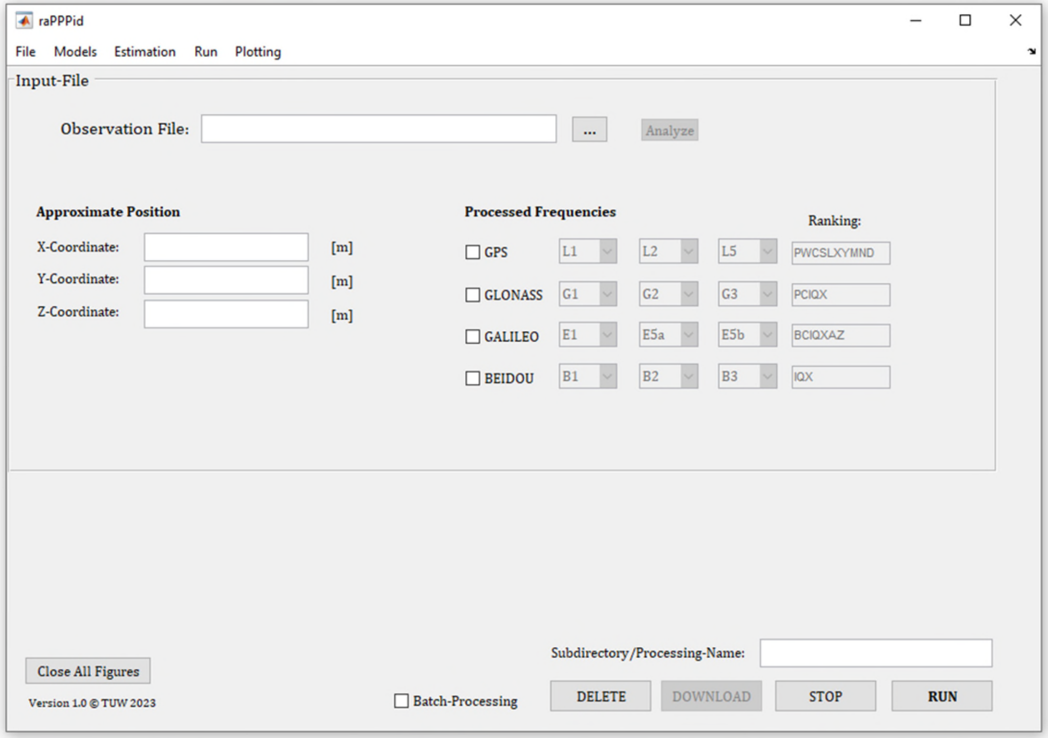
Test Environment

Smartphone	Google Pixel 7 Pro
Data	April 4, 2023 and December 12, 2023 60 min in total, recorded with GnssLogger
Satellite products	Galileo HAS, quasi-real-time processing
Software	raPPPid



raPPPid

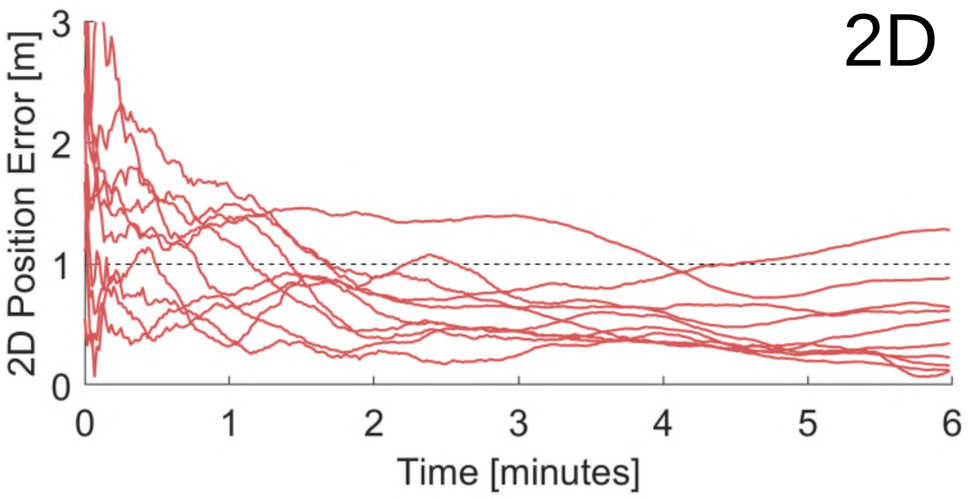
- Open-source PPP software
- GitHub:
  https://github.com/TUW-VieVS/raPPPid
- Documentation:
  https://vievswiki.geo.tuwien.ac.at/en/raPPPid

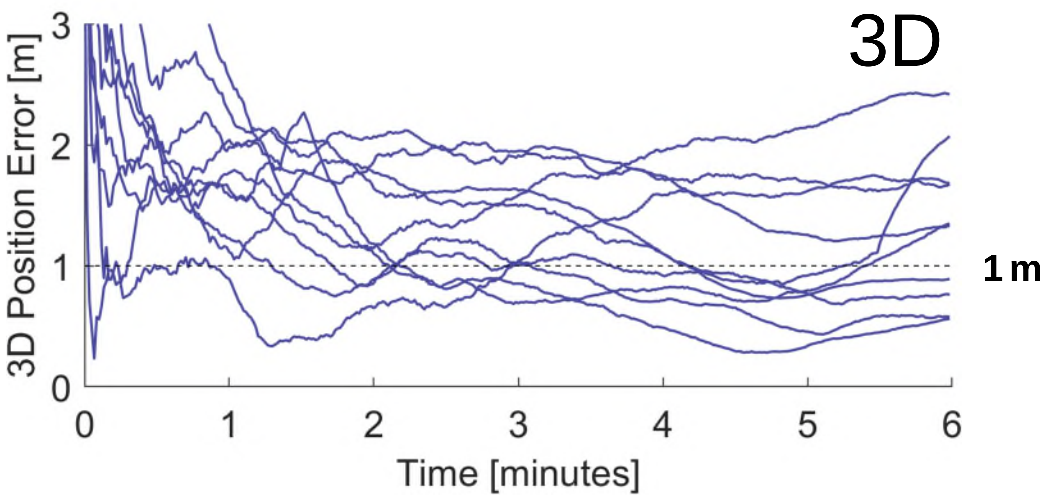


Processing Settings

Smartphone	Google Pixel 7 Pro
Date and period	April 4, 2023 and December 12, 2023; 60 minutes in total
Observation interval	1 second, reset of the solution every 6 minutes / no reset
Processed measurements	GPS (C1C, L1C + C5Q, L5Q), Galileo (C1C, L1C + C5Q, L5Q)
Satellite products	Galileo HAS, real-time correction stream
Processing mode	Static / static-kinematic, quasi-real-time
Observation model	Uncombined model with ionospheric constraint
Raw observation noise	Code: 7 m, phase: 0.01 m, ionosphere: 3 m
Observation weighting	$10^{-\frac{\max(0\,;\,55-SNR)}{a}}$, with a = 10
Ionosphere model	IGS RT GIM, released after 1 min
Troposphere model	GPT3, ZWD estimated
Correction models	Solid Earth tides, relativistic effects, Phase Wind-Up
Satellite exclusion	C/N0 < 20 dB.Hz or elevation < 10°
Data quality checks (thresholds)	Observed minus computed (code: 25 m, phase 5 m), code triple-time difference (35 m), cycle-slip detection with $dL_i - dL_j$ (5 cm) and Doppler (0.8 cy)

Results (Galileo HAS)





median 2D error: 62 cm

median 3D error: 138 cm

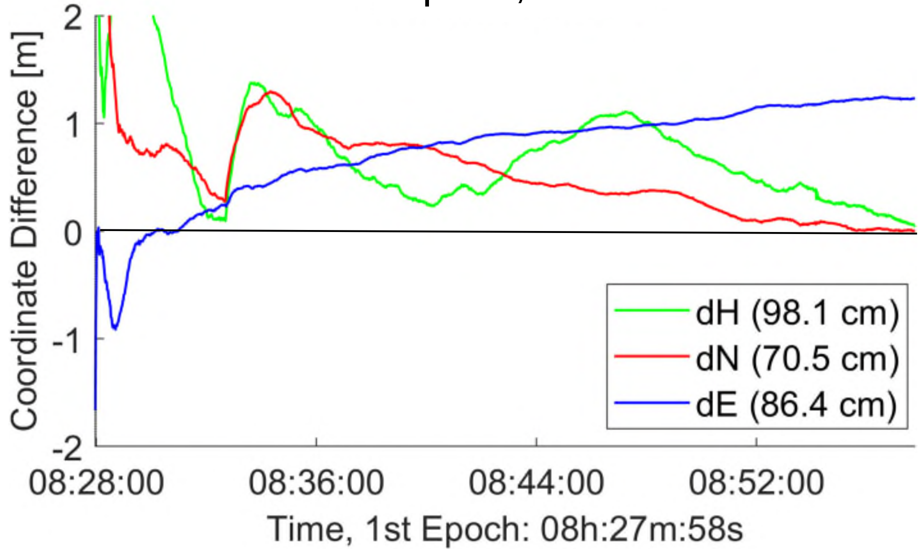
mean convergence: 71 s

static, reset every 6 minutes

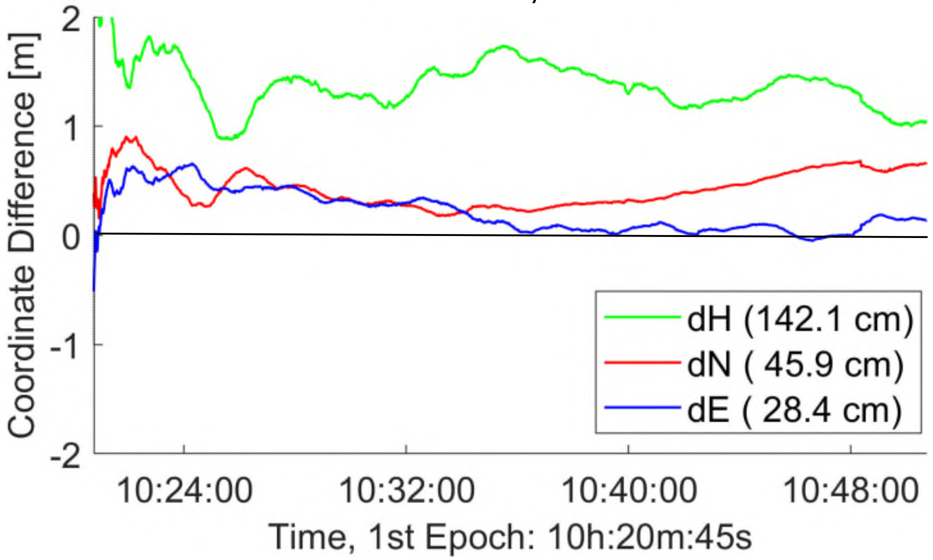
convergence: 2D < 1m

Results (Galileo HAS)

April 4, 2023



Dec 12, 2023

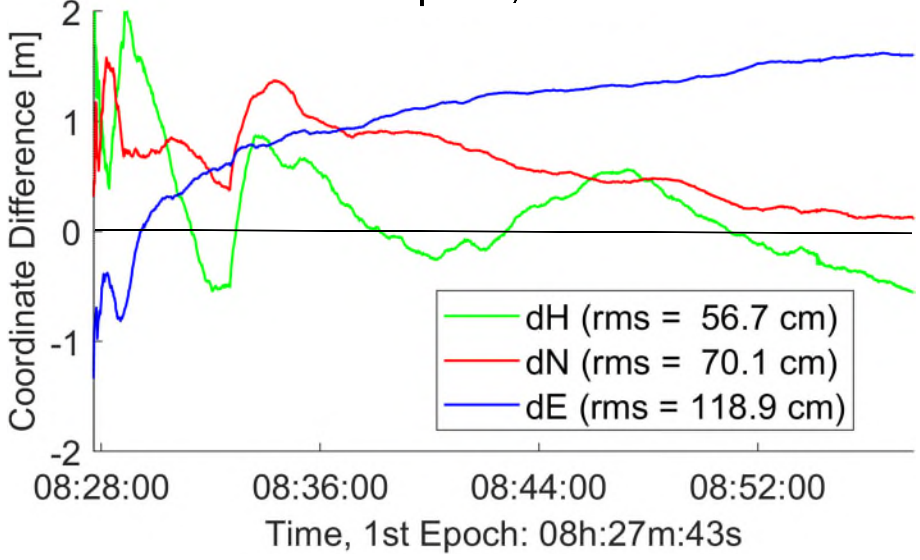


(rms)

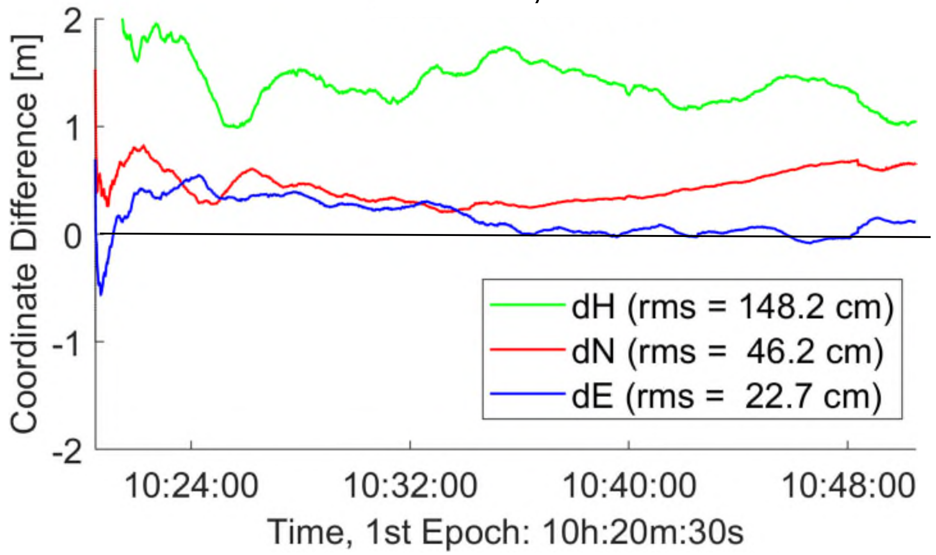
static-kinematic, no reset

Results (CODE MGEX, final product)

April 4, 2023



Dec 12, 2023



(rms)

static-kinematic, no reset

Summary

Google Pixel 7 + good conditions + Galileo HAS + raPPPid ⇒

2D < 1 m

3D ~ 1 m

convergence time: 1-2 minutes

→ Refine observation model

→ Kinematic and challenging environments

→ Include other sensors (e.g., accelerometer)

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Thank you
for your attention!

References

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