Smartphone PPP with the Galileo HAS

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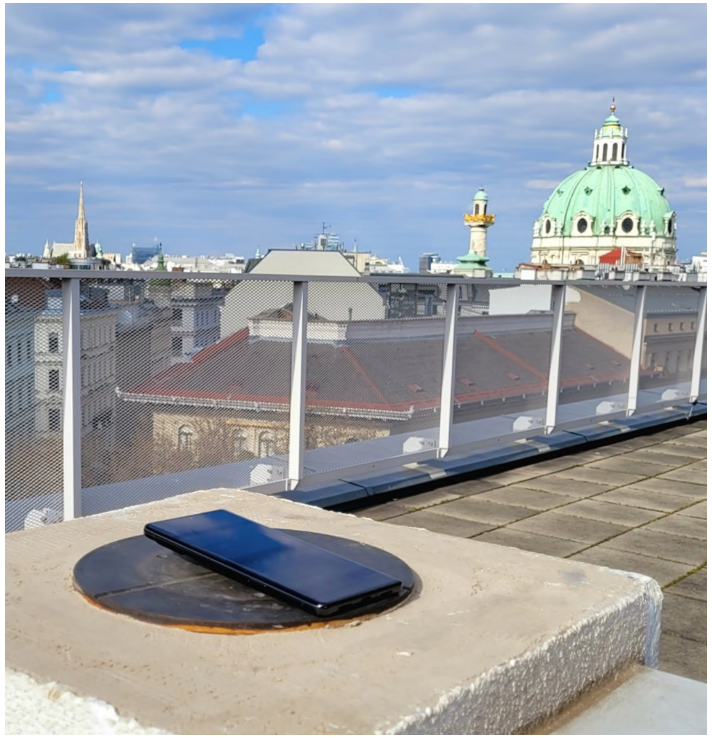
- Introduction
- Challenges
- Results
- Summary

Smartphone + GNSS

- Since 2016, Android allows accessing the raw GNSS measurements
- Self-developed PVT algorithms
- Application of correction data

→ improve positioning performance



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Precise Point Positioning

PPP relies on:

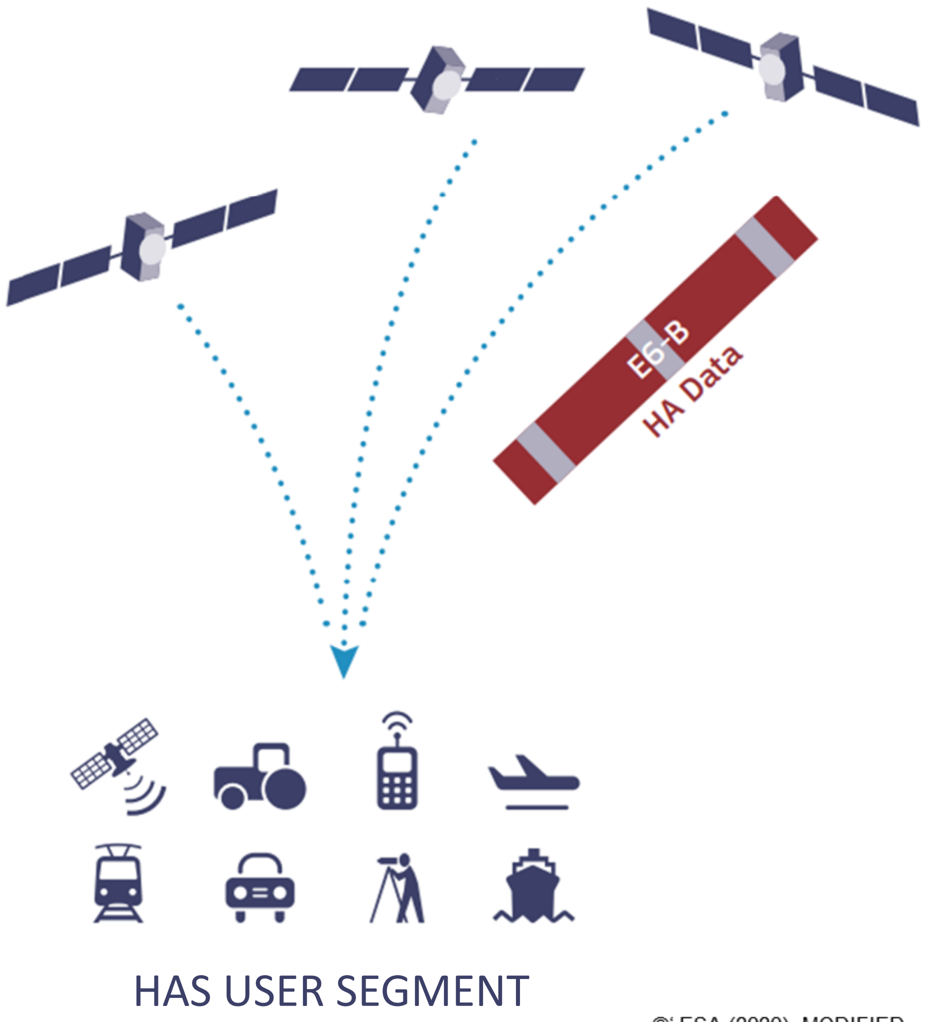
- Precise satellite products: orbits, clocks and biases
- Complex models and algorithms

Geodetic accuracy: cm, or even mm

Major drawback: convergence time

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)



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Galileo HAS

HAS	SERVICE LEVEL 1	SERVICE LEVEL 2
COVERAGE	Global	European Coverage Area (ECA)
TYPE OF CORRECTIONS	PPP - orbit, clock, biases (code and phase)	PPP - orbit, clock, biases (code and phase) incl. atmospheric corrections
SUPPORTED FREQUENCIES	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C
HORIZONTAL ACCURACY 95 %	<20 cm	<20 cm
VERTICAL ACCURACY 95 %	<40 cm	<40 cm
CONVERGENCE TIME	<300 s	<100 s
AVAILABILITY	99 %	99 %
USER HELPDESK	24/7	24/7

Initial service (since January 2023)

Full service (planned for 2024)

Depending on:

- PPP software
- GNSS equipment

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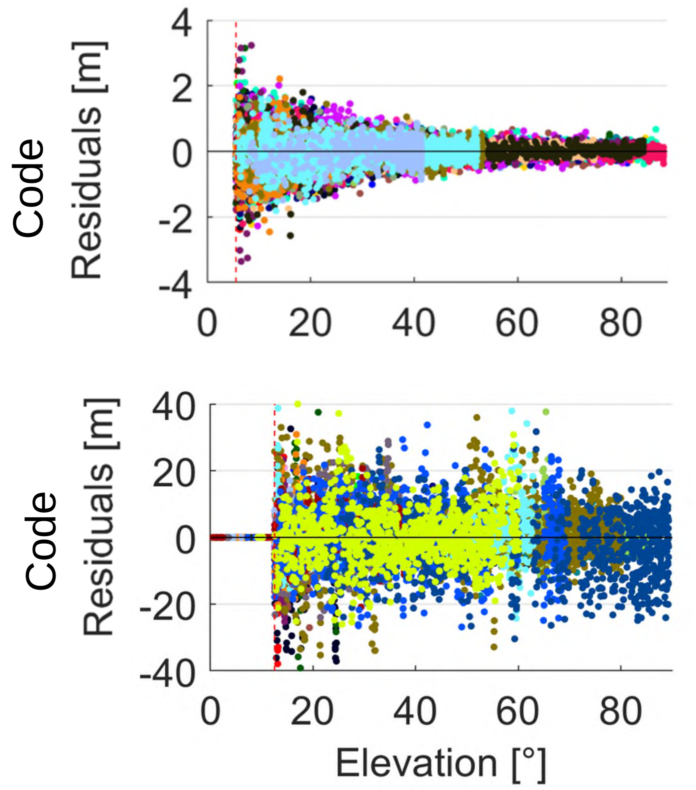
Challenges

- Observation generation
  - Android API provides time-stamps
  - Generation of pseudorange is tricky[1]
- Observation quality:
  - Factor 10-100 worse
  - C/N0: ~10 dBHz lower
- Observation weighting
- …



[1] more details: (Zangenehnejad et al., 2023)

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Quality Checks

- Code Triple-Time Difference: $(C_i - C_{i-1}) - (C_{i-2} - C_{i-3}) < 35\ m$
- Observed-minus-computed: $C - C_{model} < 25\ m$

  $L - L_{model} < 5\ m$

Cycle-Slip Detection

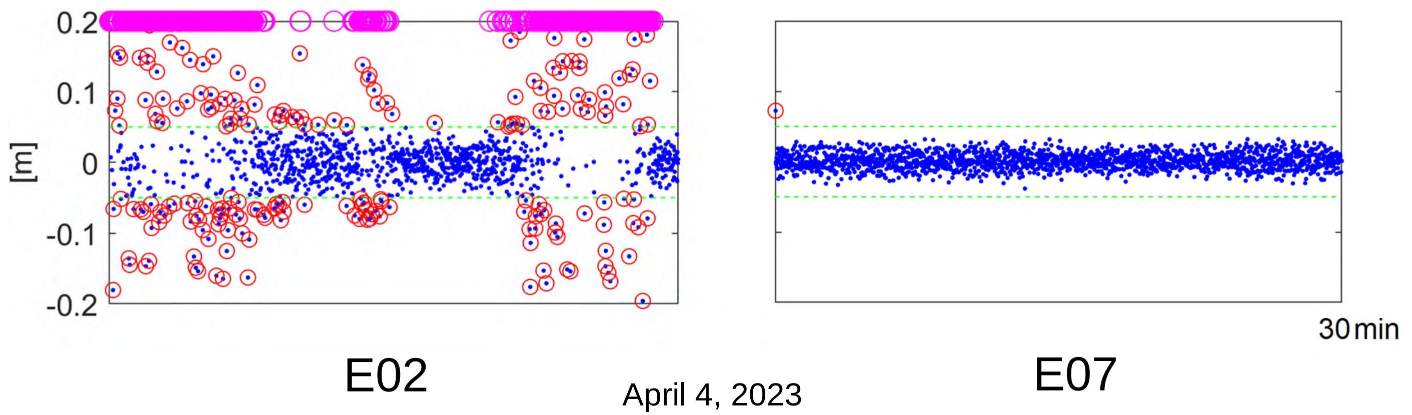
$$L_{old} + dt\sqrt{D_{now} D_{old}} < 0.8\ cy$$

… with Doppler-Shift

$$dL_{E1} - dL_{E5a} < 0.05\ cm$$

… with phase difference

dL_{E1} - dL_{E5a}



April 4, 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

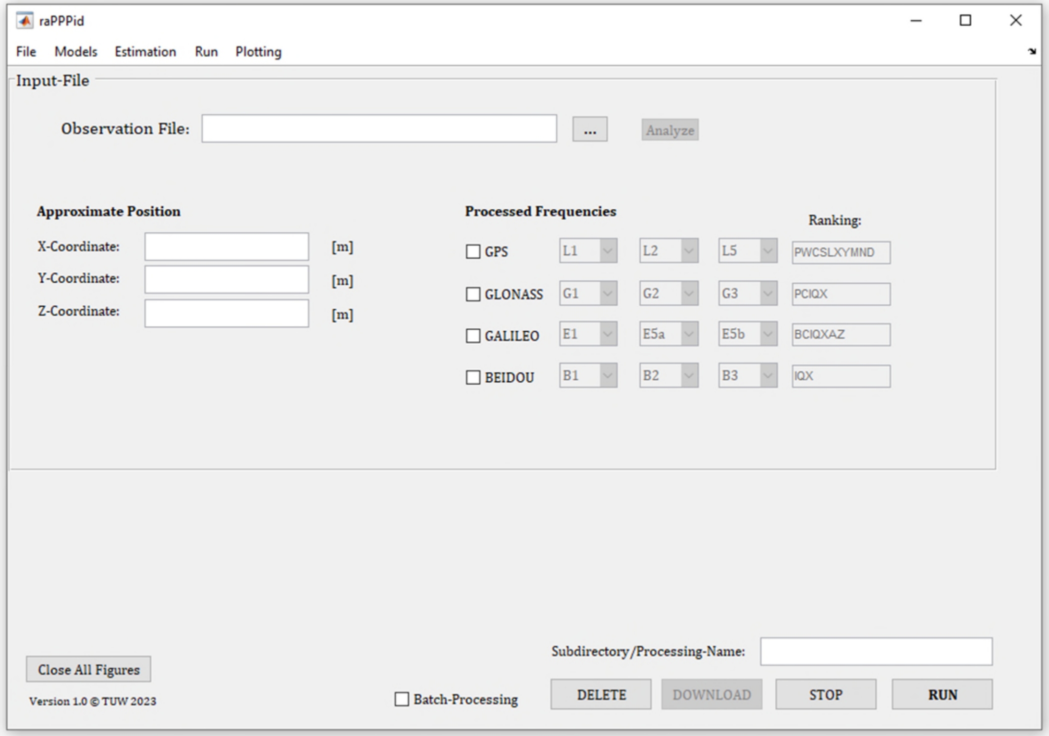
Processing Settings

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)

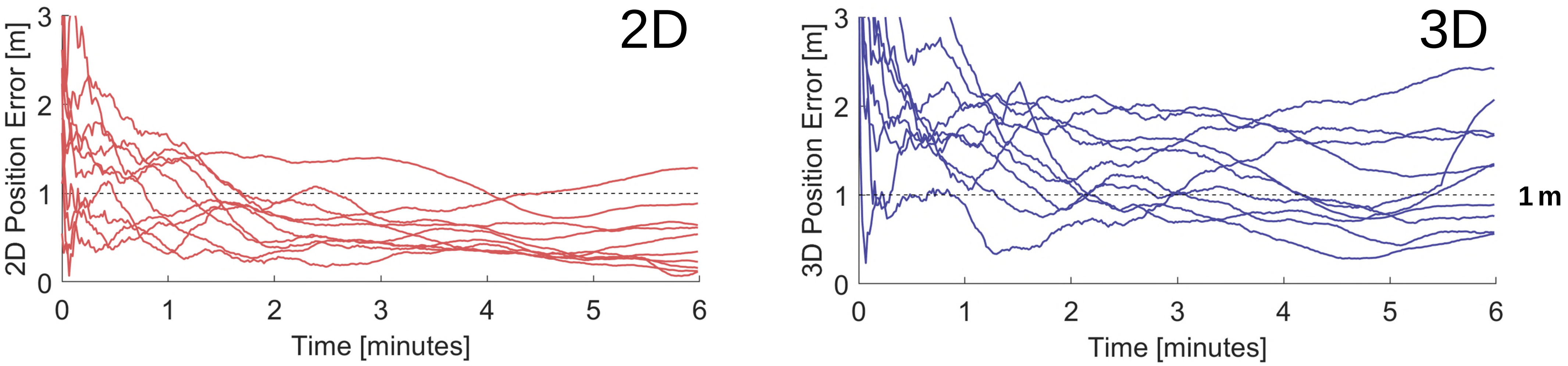
TU WIEN VieVS
Vienna VLBI and Satellite Software

raPPPid

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



Results



median 2D error: 62 cm

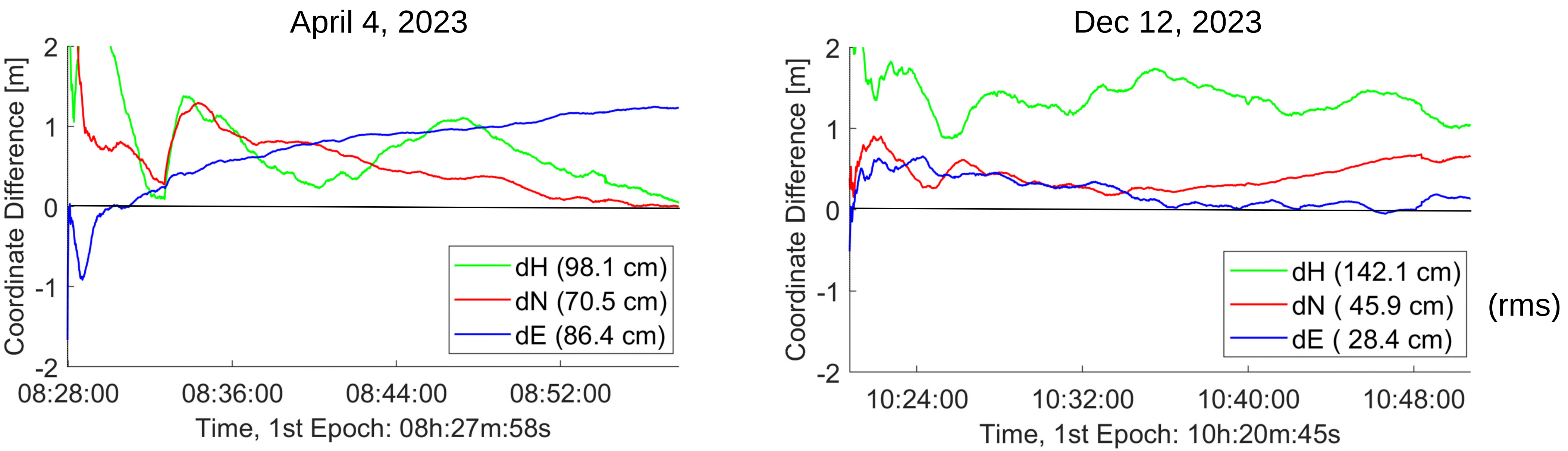
median 3D error: 138 cm

mean convergence: 71 s

static, reset every 6 minutes

convergence: 2D < 1m

Results



static-kinematic, no reset

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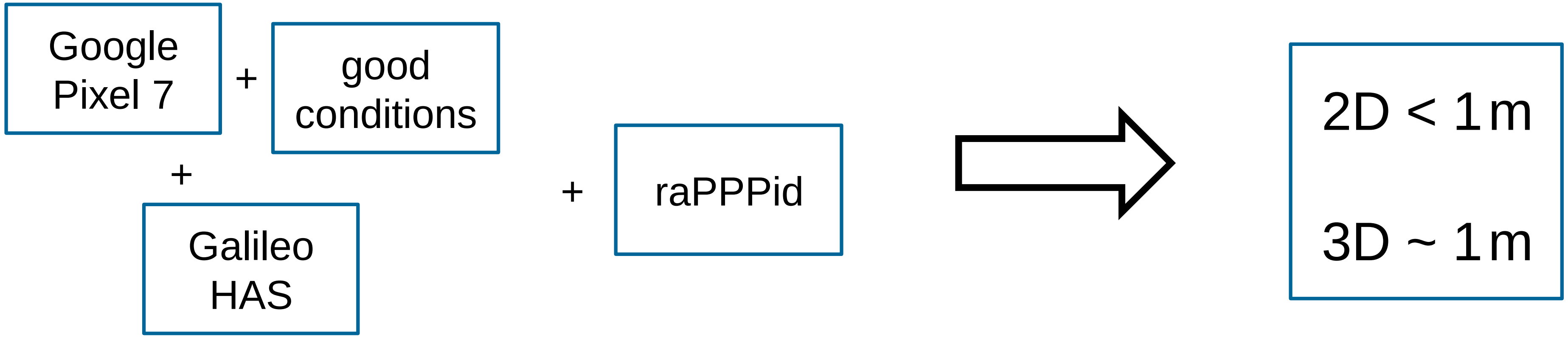
Summary



Future investigations:

- Refine observation model (e.g., observation weighting)
- Kinematic and challenging environments
- Include other sensors (e.g., accelerometer)

References

- Glaner, M. F., & Weber, R. (2023). Breaking the One-Meter Accuracy Level with Smartphone GNSS Data. Engineering Proceedings, 54(1). https://doi.org/10.3390/ENC2023-15465
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Thank you

for your attention!

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