



Precise Point Positioning

Die präzise Einzelpunktbestimmung

Gliederung

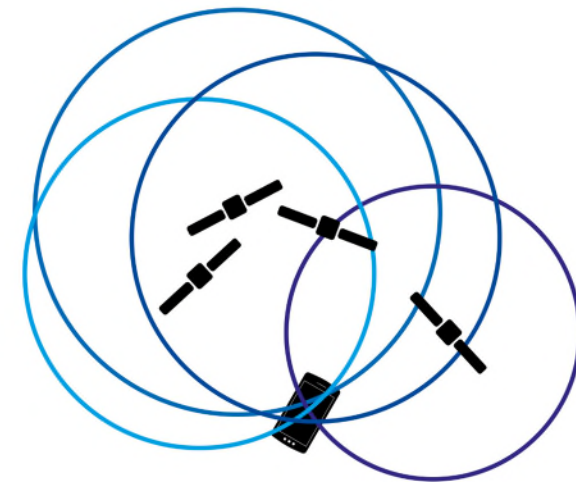
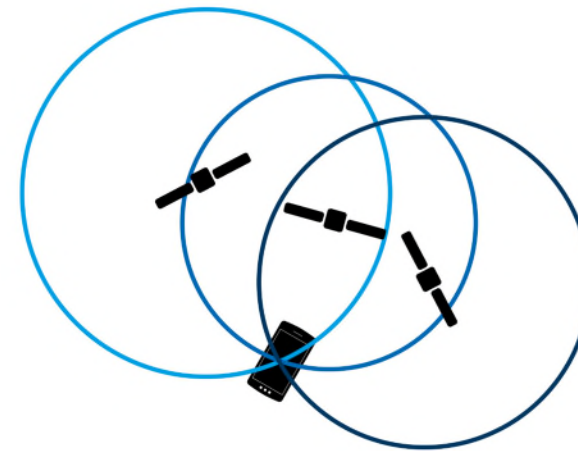
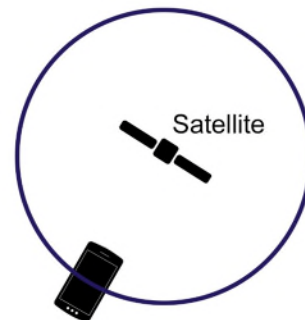
- Grundlagen
- PPP Theorie
- Ergebnisse
- Ausblick

Gliederung

- Grundlagen
- PPP Theorie
- Ergebnisse
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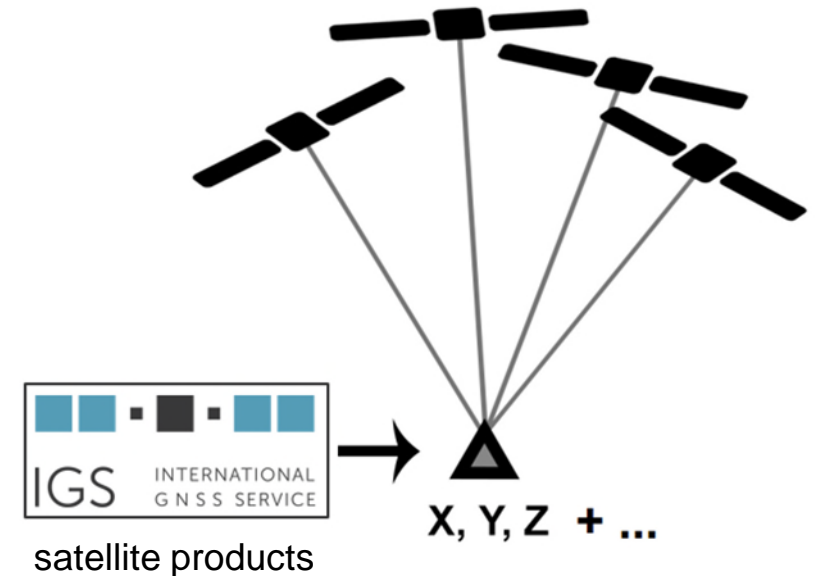
Einfache GNSS Positionierung

- GPS, GLONASS, Galileo und BeiDou
- Satellitenposition und –uhr sind bekannt
- Signallaufzeit wird gemessen
- Pseudorange



Precise Point Positioning

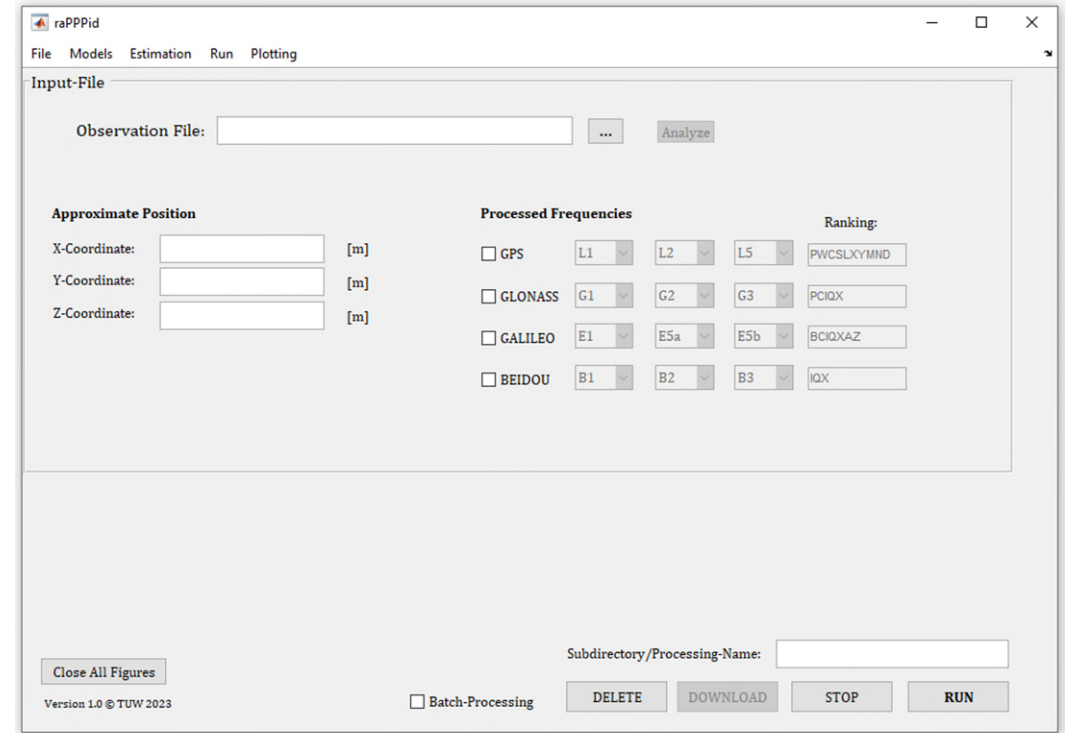
- PPP basiert auf präzisen Satellitenprodukten:
Satellitenorbits, -uhren und -biases
- komplexe Modelle und Algorithmen
- Genauigkeit: cm oder sogar mm
- Größter Nachteil: Konvergenzzeit



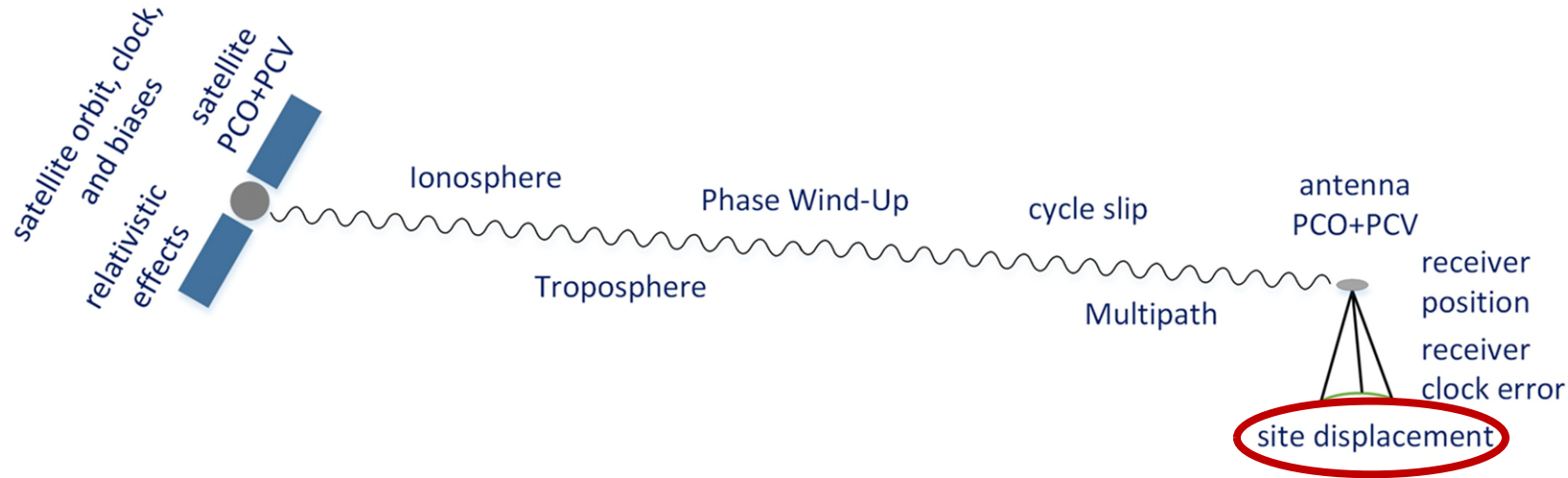
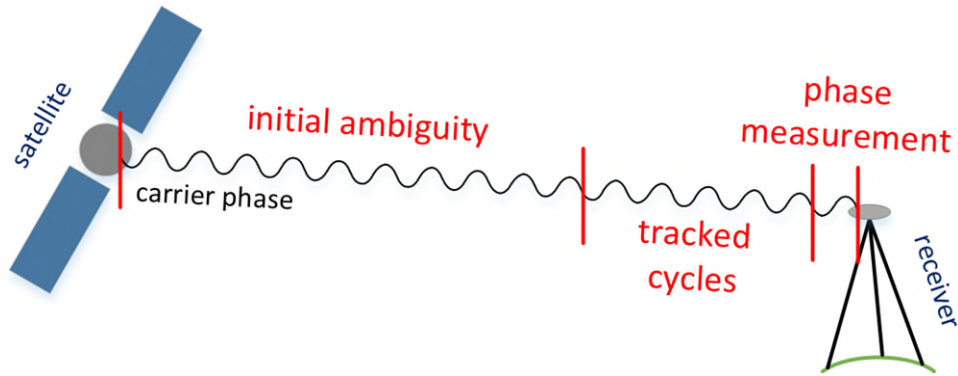


raPPPid

- open-source PPP Software
- selbstentwickelt
- PPP Modul der VieVS
- GitHub:
<https://github.com/TUW-VieVS/raPPPid>
- Documentation:
<https://viewswiki.geo.tuwien.ac.at/en/raPPPid>



Messungen + Fehlerquellen



- Code
- Phase
- Signal-to-Noise ratio
- Doppler

→ ziemlich viele

Fehlerquellen

| Symbol | Description | Magnitude |
|--|-----------------------------------|--|
| ρ | Theoretical distance | 10^7 m |
| dt^S | Satellite clock error | μs - ns |
| dt_{rel} | Relativistic effects | 10 ns |
| dt_R^{GPS} | Receiver clock error | ns-ms |
| δt^g | Receiver offset GNSS | ns |
| $-DCB_{\Pi}$ | Receiver DCB | ns |
| $dIono_1$ | Ionospheric delay | 1-20 m |
| $dTrop$ | Tropospheric delay | 1-15 m |
| $dTrop_{residual}^{wet}$ | Residual wet delay | mm-dm |
| $\delta\rho_{solid}$ | Solid Earth tides | cm |
| $\delta\rho_{GDV_i}$ | Group Delay Variations | mm-1 m |
| $\delta\rho_{oceanloading}$ | Ocean loading | mm-cm |
| $\delta\rho_{PCO_i,PCV_i}^S$ | Satellite PCO and PCV | 1 m, mm-cm |
| $\delta\rho_R^{PCO_i,PCV_i}$ | Receiver PCO and PCV | cm-dm, mm-cm |
| $\delta\rho_R^{ARP_i}$ | Receiver ARP (height) | cm-1 m |
| $\delta\rho_{wind-Up_i}$ | Phase Wind Up | cm-dm |
| N_i | Phase Ambiguity | - |

(beinhaltet Satelliten- und User-Position)

→ der Rest wird als
Unbekannte geschätzt

Gliederung

- Grundlagen
- PPP Theorie
- Ergebnisse
- Ausblick

PPP Modelle

Conventional

- Ionosphärenfreie Linearkombination
- Ionosphäre 1.Ordnung eliminiert
- etabliert und praktisch
- nur für zwei Frequenzen

IF

Uncombined

- rohe Beobachtungen
- Ionosphäre geschätzt
- moderner Ansatz
- jegliche Anzahl an Frequenzen

UC

$$P_{IF} = \rho + c(dt_R^{GNSS_1} + \delta t_R^g) + dTrop^{wet} + \varepsilon$$

$$L_{IF} = \rho + c(dt_R^{GNSS_1} + \delta t_R^g) + dTrop^{wet} + \underbrace{\lambda_{IF} N_{IF}}_{\text{float}} + \varepsilon$$

IF

Conventional model

Uncombined model

UC

$$P_i = \rho + c(dt_R^{GNSS_1} + \delta t^g) - DCB_{1i} + dTrop^{wet} + \gamma_{1i} \cdot dIono_1 + \varepsilon$$

$$L_i = \rho + c(dt_R^{GNSS_1} + \delta t^g) - DCB_{1i} + dTrop^{wet} - \gamma_{1i} \cdot dIono_1 + \underbrace{\lambda_i N_i}_{\text{float}} + \varepsilon$$

+

ionospheric pseudo-observations

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

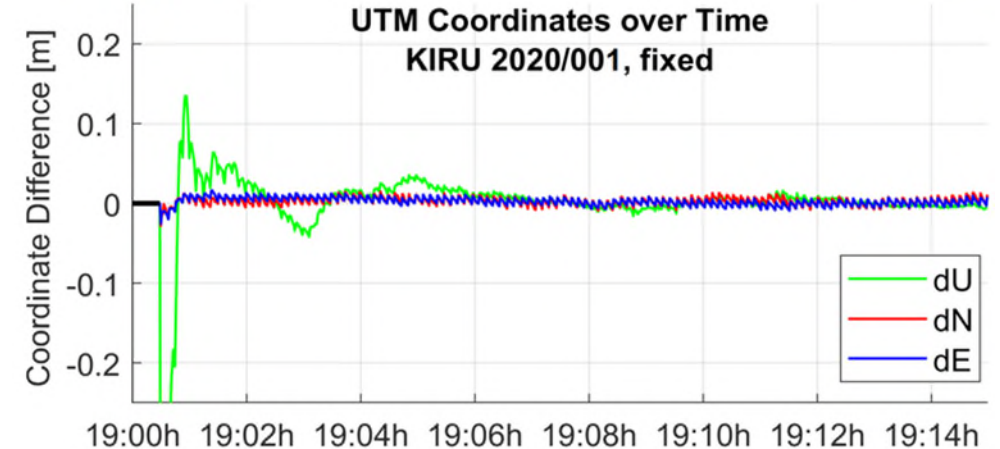
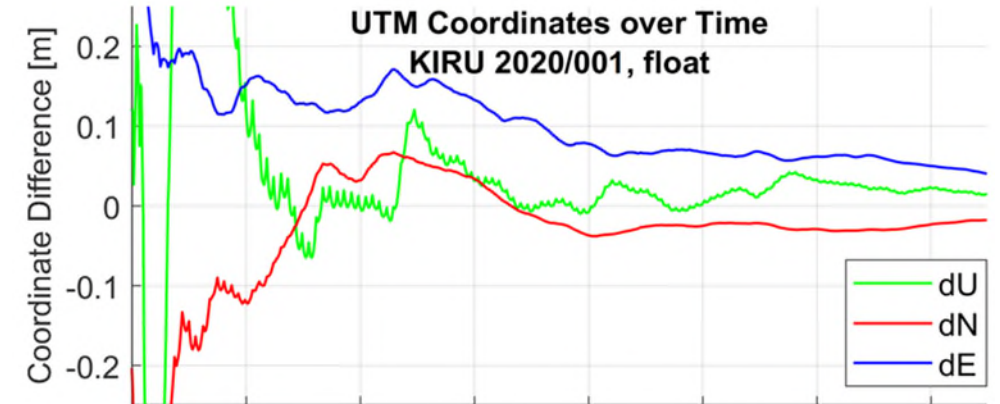
→ uncombined model with ionospheric constraint

Float solution

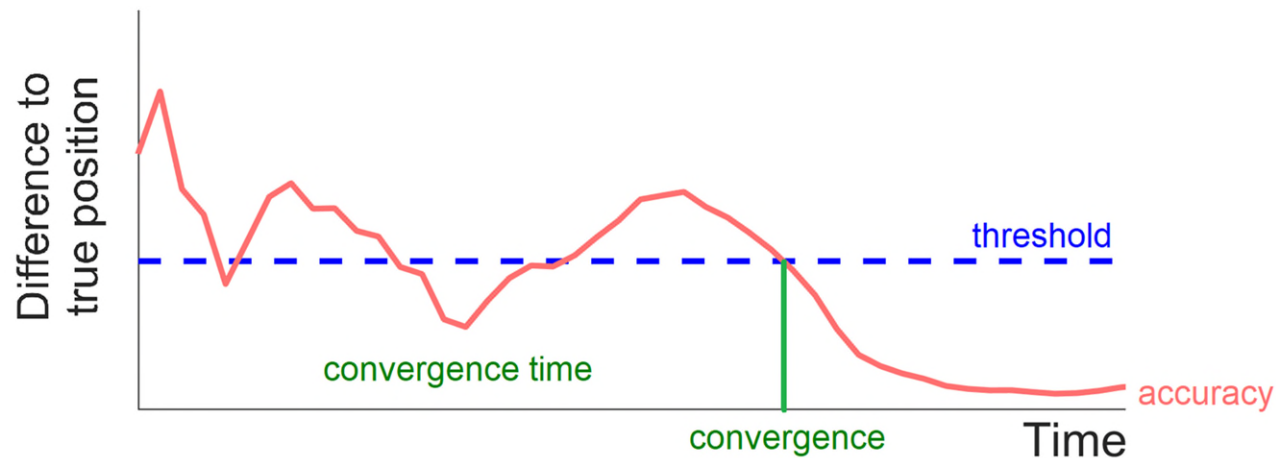
- Extended Kalman Filter

Fixed solution

- Least-Square-Adjustment
- fixierte Phasen-Mehrdeutigkeiten werden als Pseudobeobachtungen eingeführt



Konvergenz und Genauigkeit

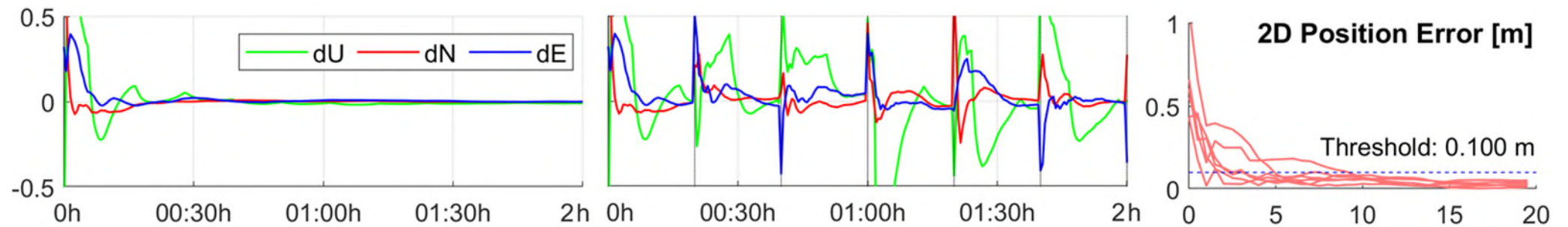


Konvergenz ist erreicht, wenn der Positionsfehler einen gewissen Grenzwert unterschreitet und auch darunter bleibt:

2D < 10 cm / 5 cm

float / fixed

Wie wir die PPP Performance untersuchen können:



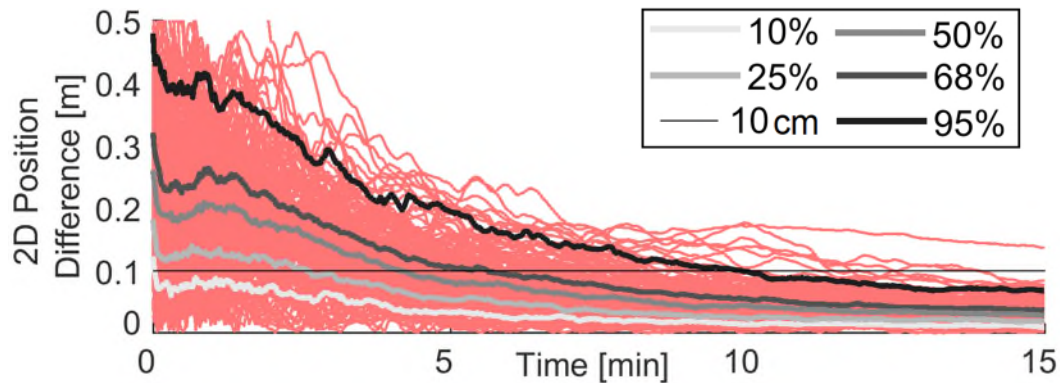
+ Referenzwerte (z.B. Koordinaten)

Gliederung

- Grundlagen
- PPP Theorie
- Ergebnisse: geodätisch
- Ausblick

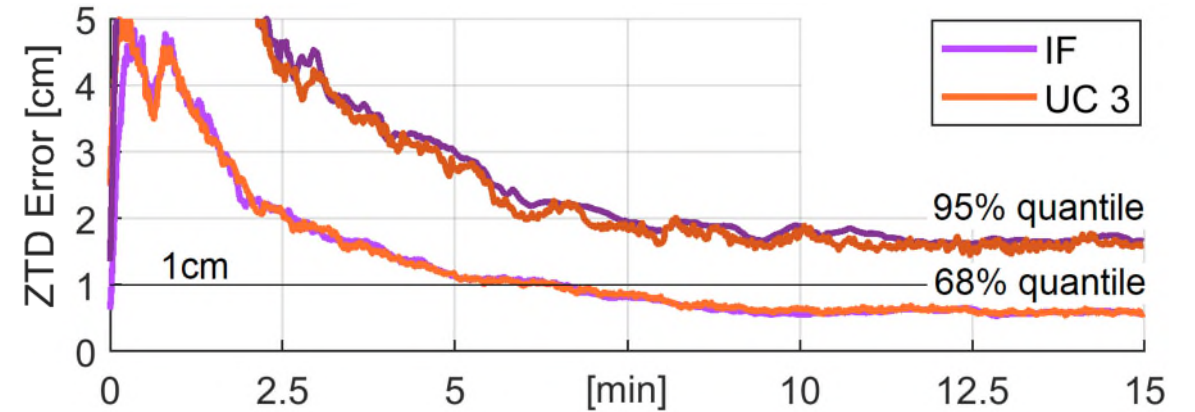
Float convergence

2D position difference



Kiruna (Sweden), UC, 3 frequencies
Dec 30+31, 2022

ZTD convergence

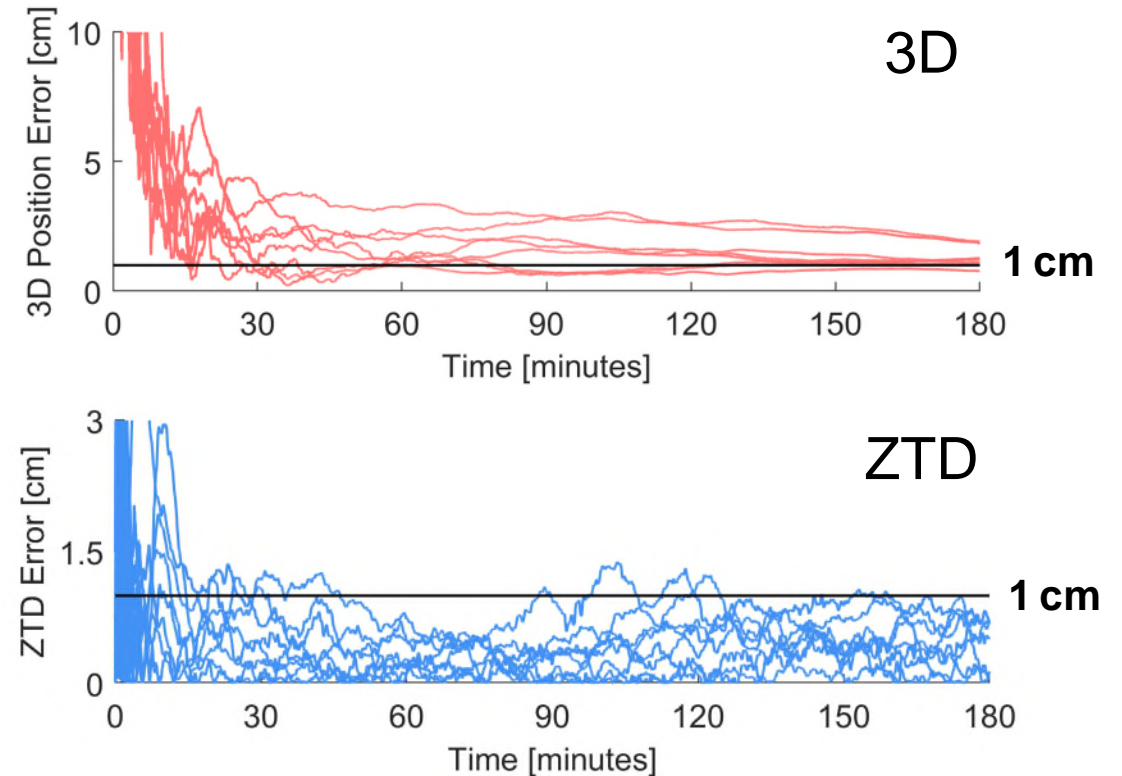


YEL2 (Yellowknife, Canada)

Dec 30+31, 2020

Float Performance

- Koordinaten und troposphärische LZV
- Langfristige Genauigkeit: 1 cm-Level oder darunter
- am Rande der Möglichkeiten von GNSS



Arequipa, Peru

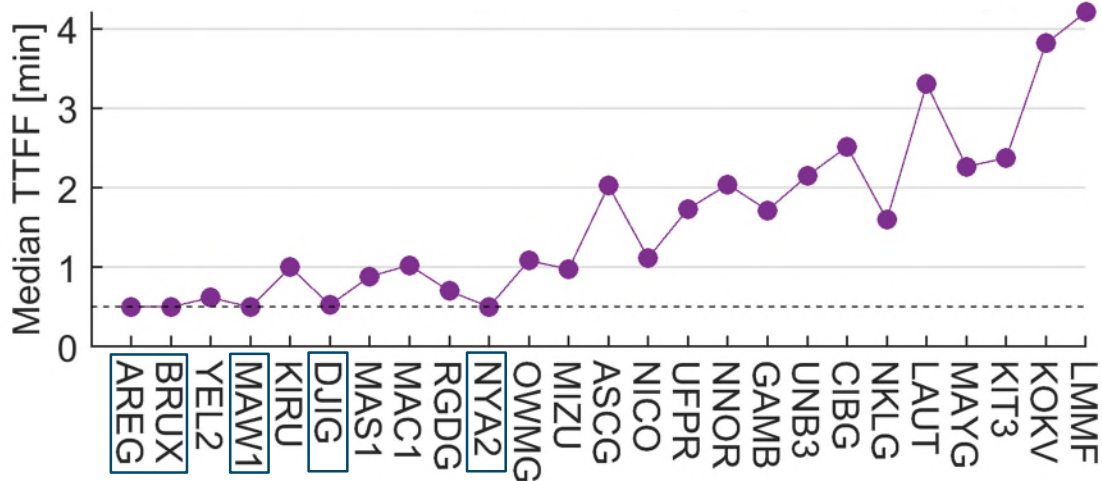
Aug 1, 2022

Median TTFF

Globaler Testfall

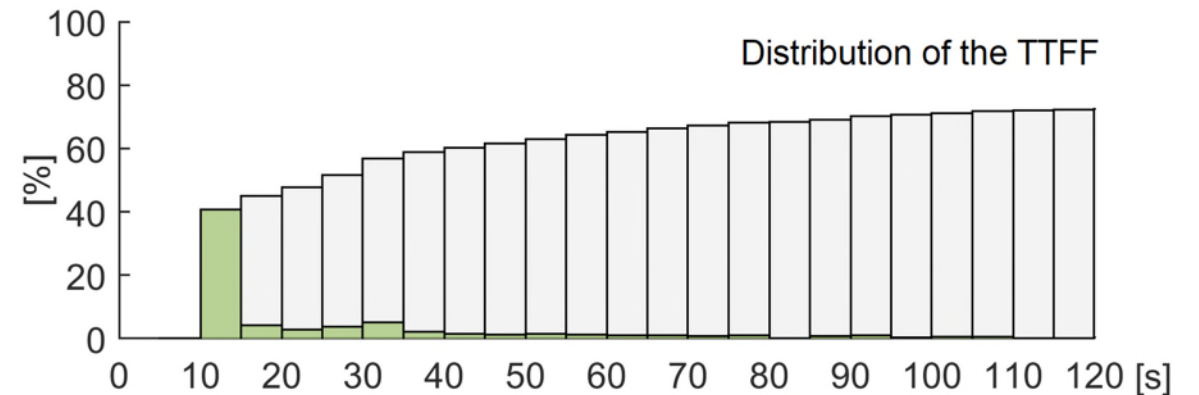
Fixing beginnt nach 30 s

Median TTFF: 30 s bis 4 min



Top-5

- lauter Septentrio PolaRx5 Receiver
- Fixing startet schon nach 10 s
→ “instantaneous”



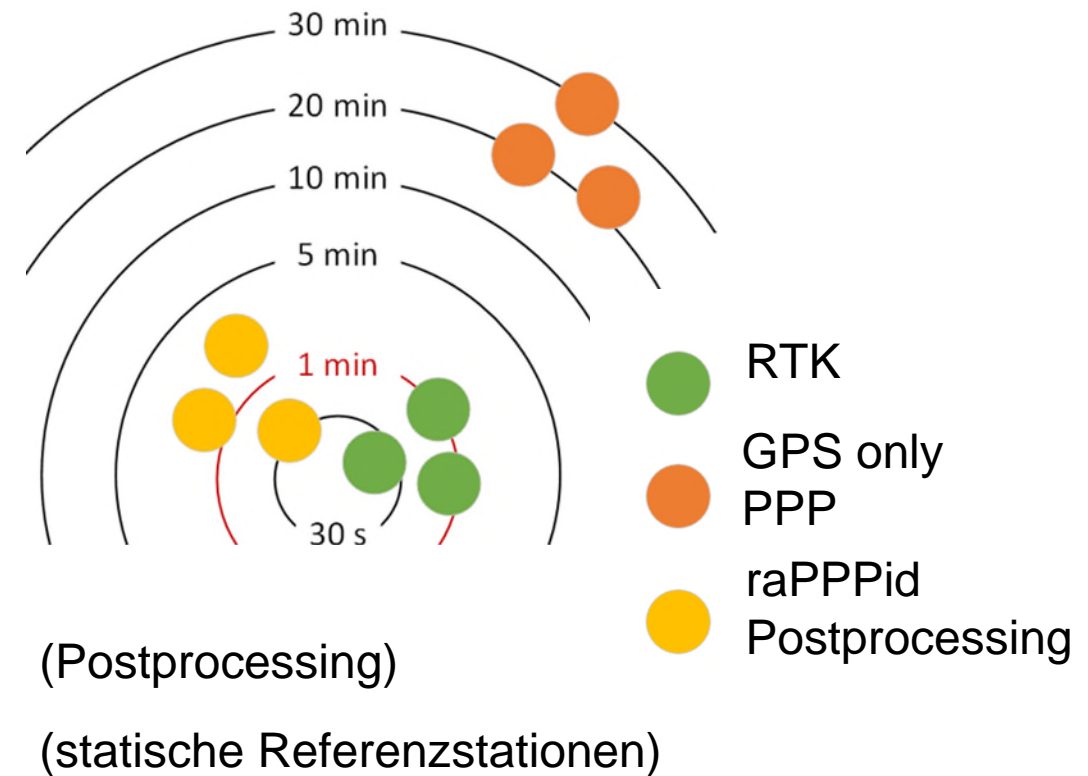
TTFF: 2D < 5cm

→ Konvergenzzeit:

- Float (2D < 10 cm): einige Minuten
- Fixed (2D < 5 cm): 1 min oder weniger

→ Genauigkeit: cm oder darunter

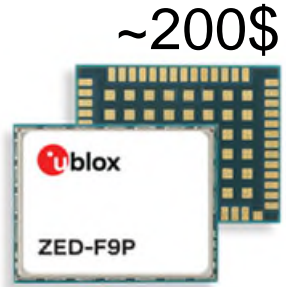
→ vergleichbar zu RTK



Gliederung

- Grundlagen
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- Ergebnisse: low-cost
- Ausblick

Low-cost equipment



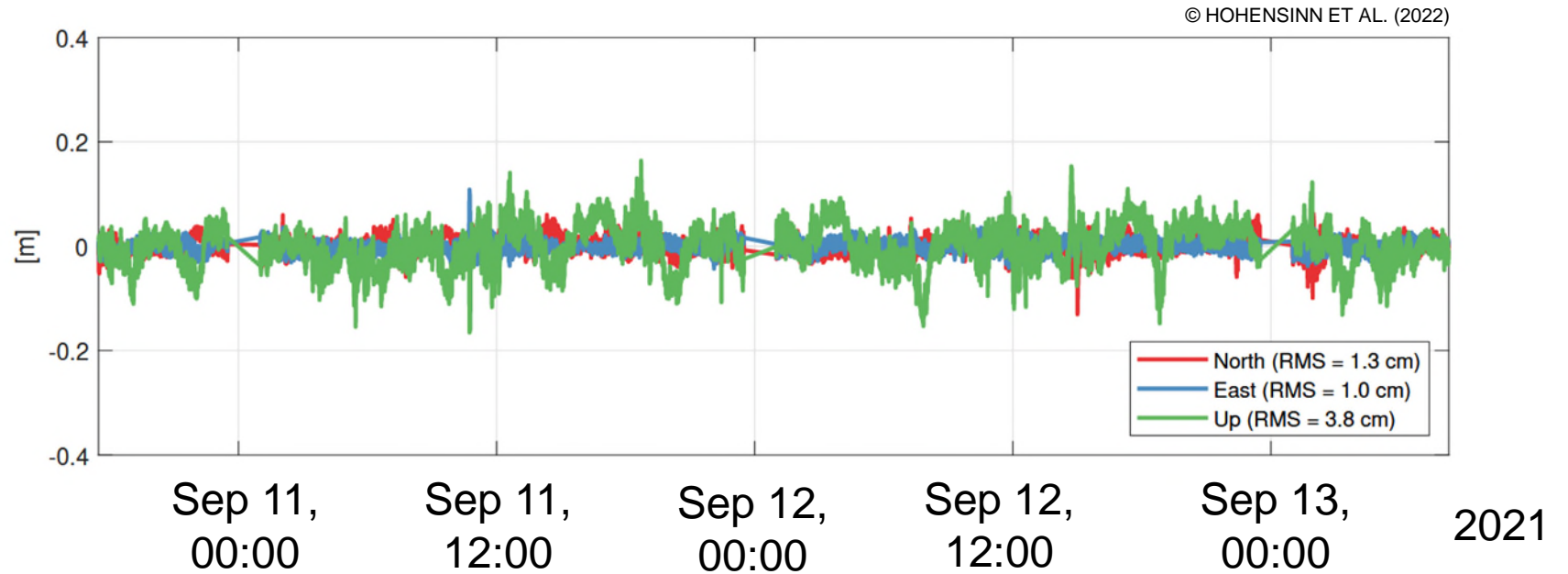
© U-BLOX (2023)

+

~100\$



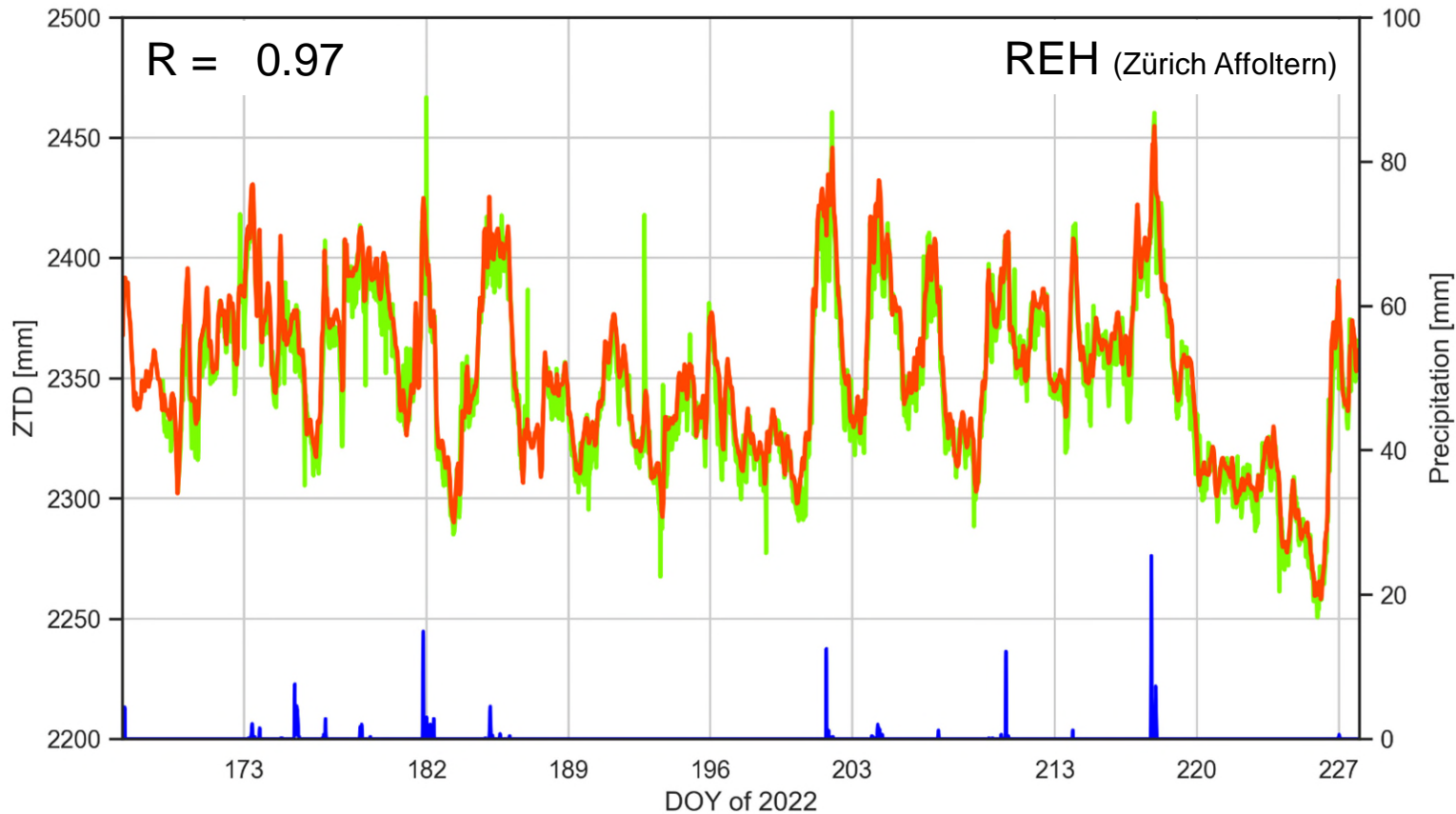
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stabile cm Genauigkeit
in Quasi-Realtime



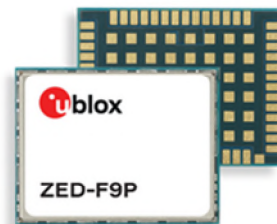
vergleichbar zu
geodätischen Equipment



raPPPid vs. Bernese

rms = 10.61
 bias = 5.06 [mm]
 std = 9.33

raPPPid (real-time settings)
 Bernese (post-processing)
 Precipitation (measured)



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Gliederung

- Grundlagen
- PPP Theorie
- Ergebnisse: ultra-low-cost
- Ausblick

Wie genau positioniert mein Smartphone?



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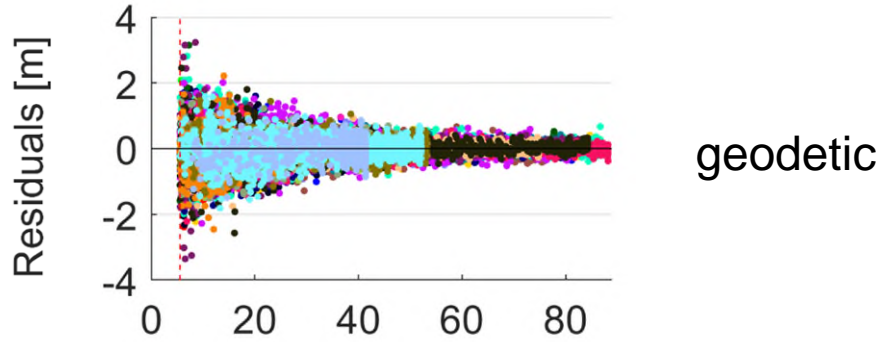
<https://kontrollpunkt.bev.gv.at/>

Smartphone + GNSS

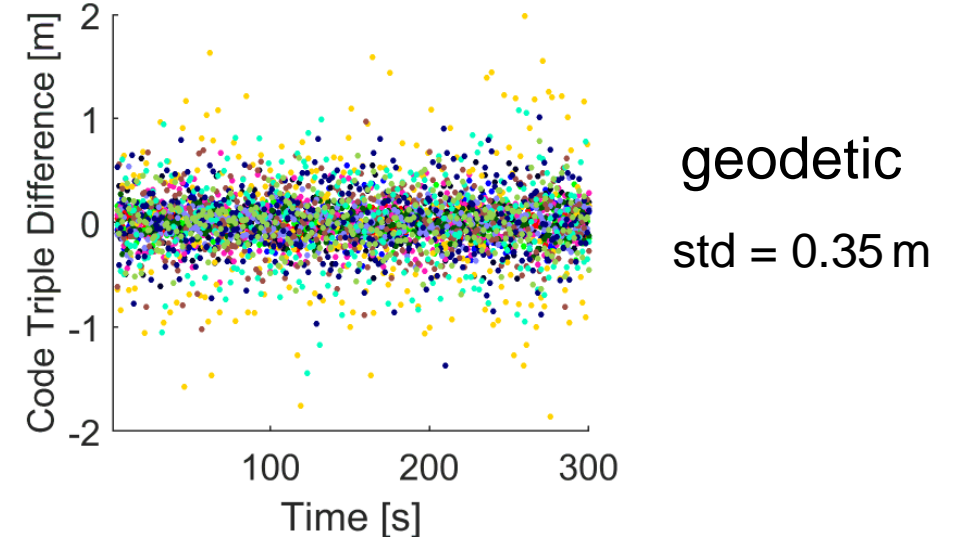
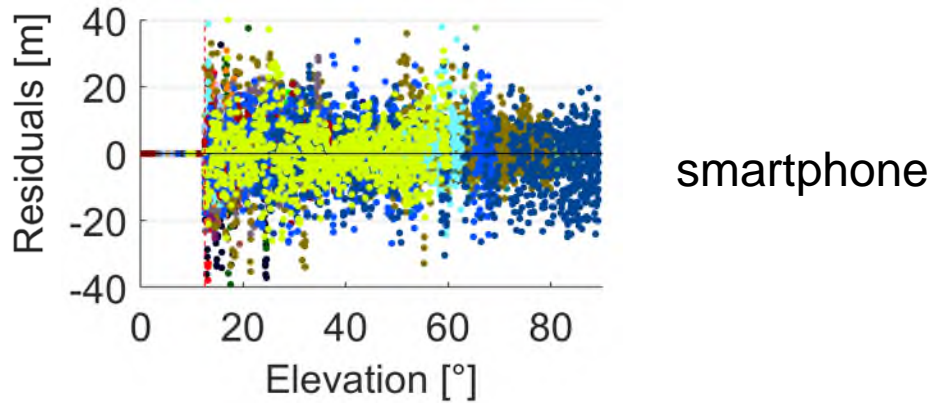
- seit 2016 erlaubt Android das Auslesen von GNSS Messungen
- erlaubt selbstentwickelte Algorithmen:
 - GNSS Beobachtungen aufzeichnen
 - PPP Prozessierung mit raPPPid
- APPP Projekt



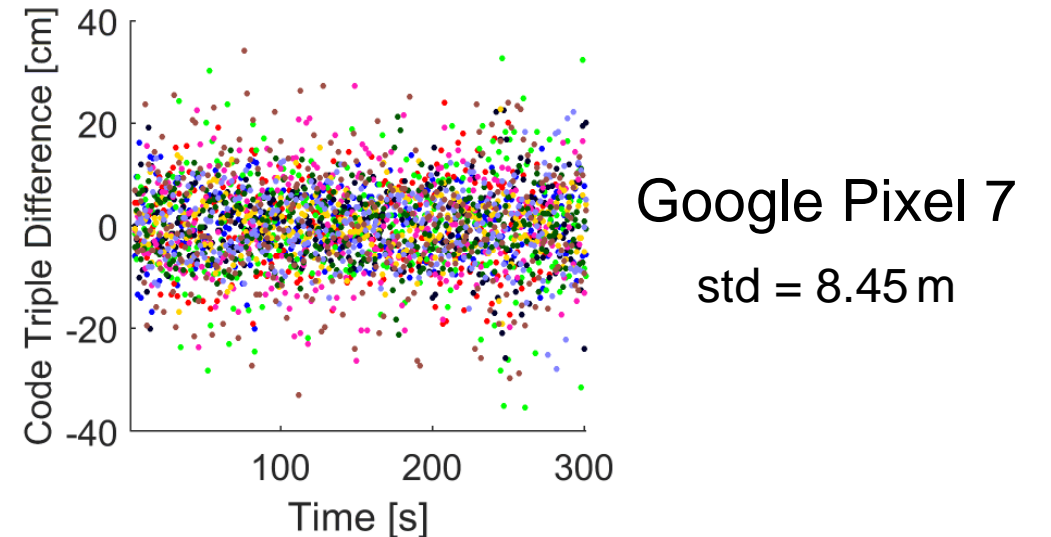
Observation quality



Code residuals over elevation



Code triple-time difference



Test Smartphones

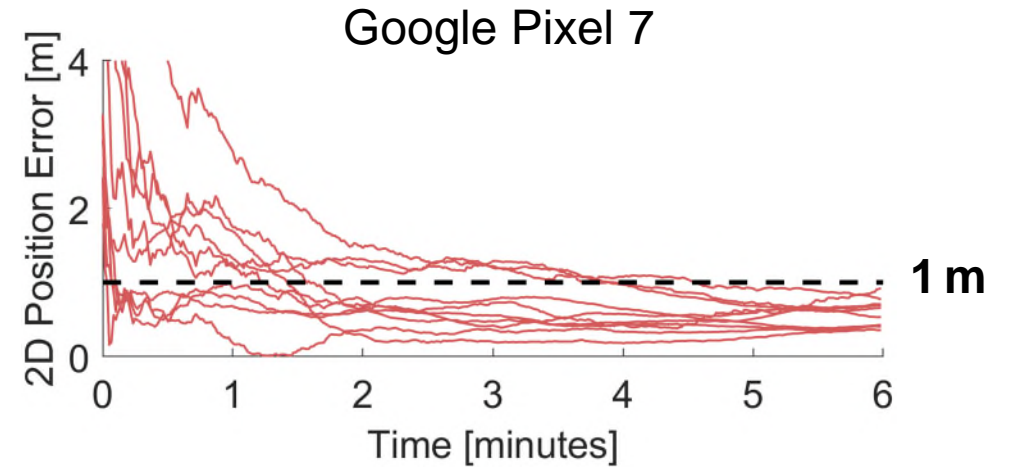
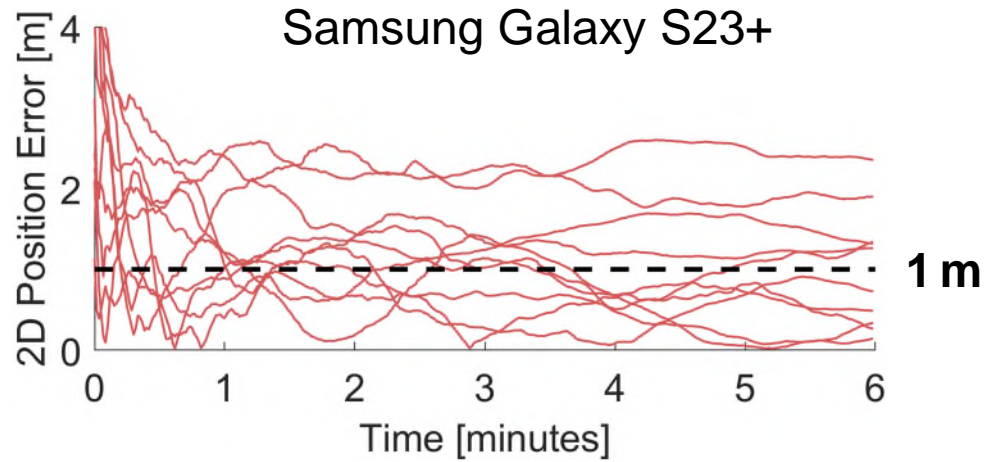


Samsung Galaxy S23+
GREC, DF, nur Code



Google Pixel 7
GREC, DF, Code + Phase

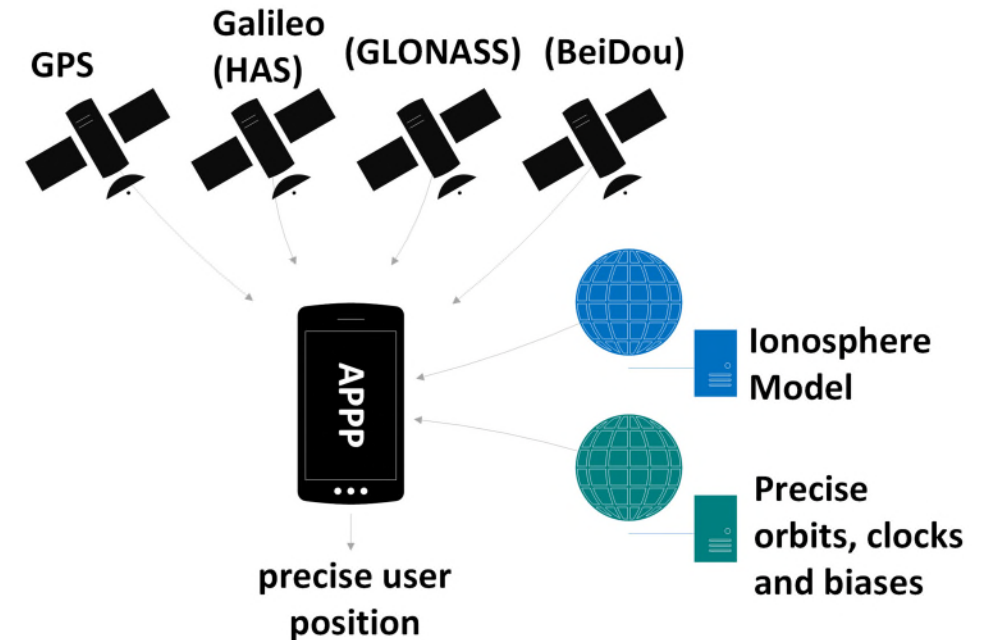
Ergebnisse (CNES RT Stream)



| Smartphone | Median 2D error [cm] | Ø 3D position error nach 6 minutes [cm] | Ø Konvergenz [min] |
|-------------|----------------------|---|--------------------|
| Galaxy S23+ | 112.5 | 258.78 | 2.33 |
| Pixel 7 | 66.54 | 108.75 | 1.70 |

APPP

- Advanced Precise Point Positioning for mass market GNSS receivers
- Ziele:
 - Android Applikation
 - PPP Berechnungen am Smartphone
 - Genauigkeit < 1 m

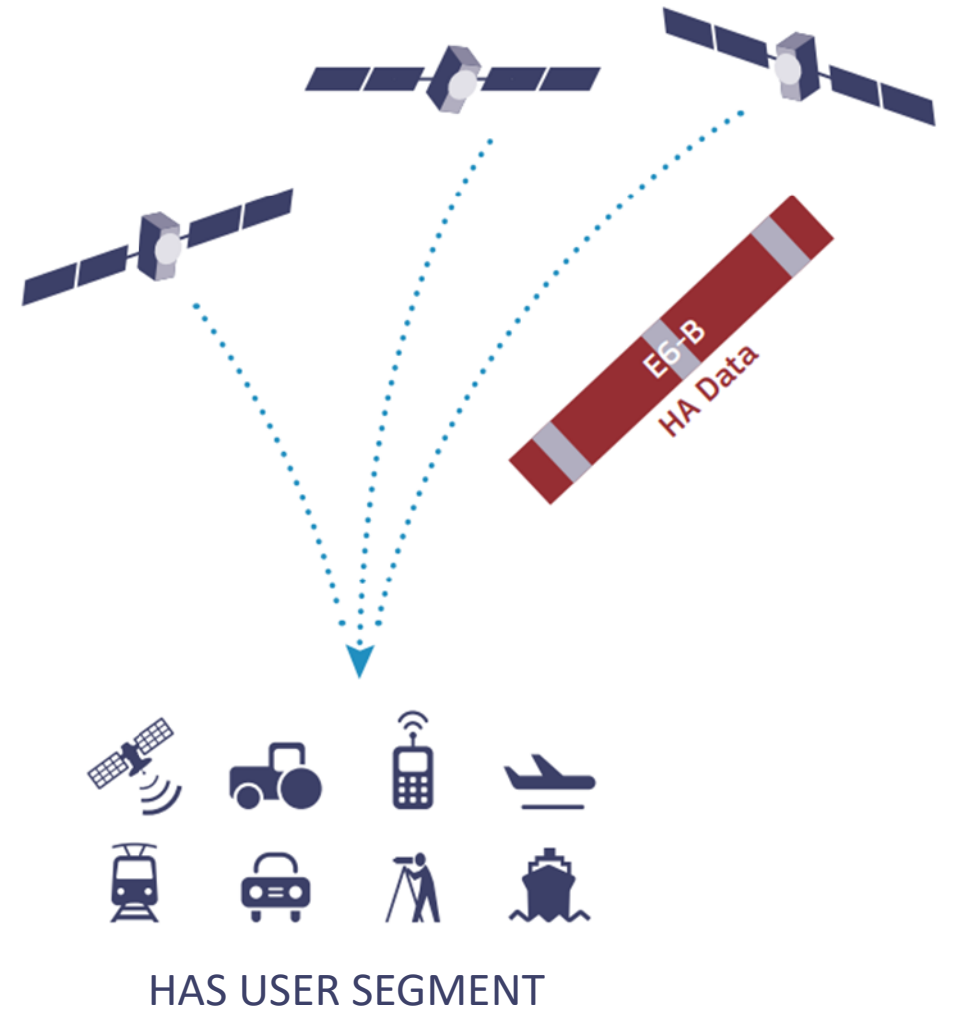


Gliederung

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- Ergebnisse: Galileo HAS
- Ausblick

Galileo High Accuracy Service

- gratis
- realtime
- Korrekturen für PPP über
 - Signal in space (E6-B)
 - das Internet (seit 24.1.2023)
- GPS und Galileo



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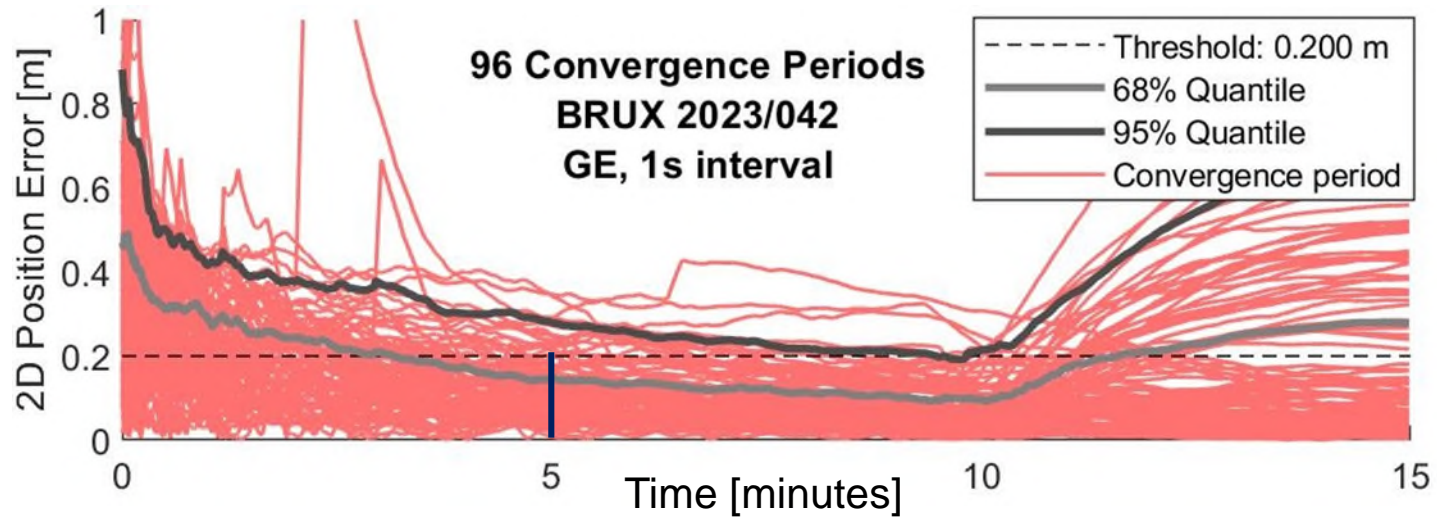
Galileo HAS

| 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 |

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Initial service
(seit Jänner 2023)

Full service
(geplant 2024)



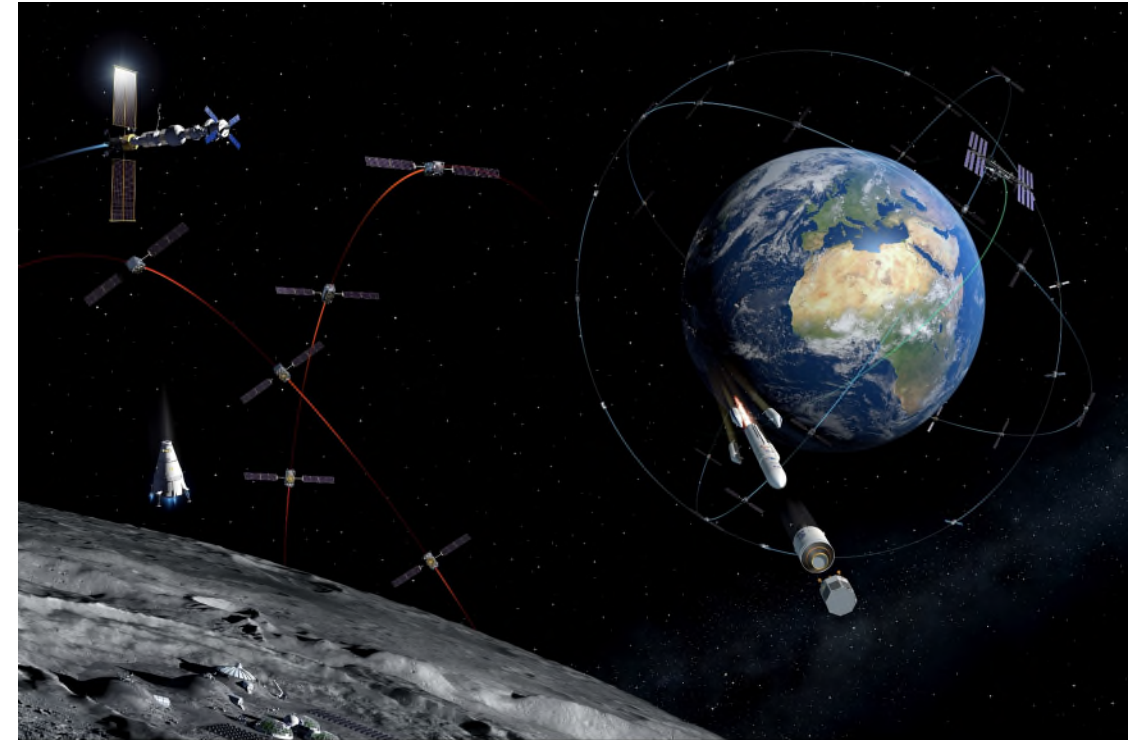
- Konvergenzzeit-Ziel ist noch nicht erreicht
- Unstimmigkeiten bei Wechsel der (Galileo) Broadcast Ephemeriden

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Potential

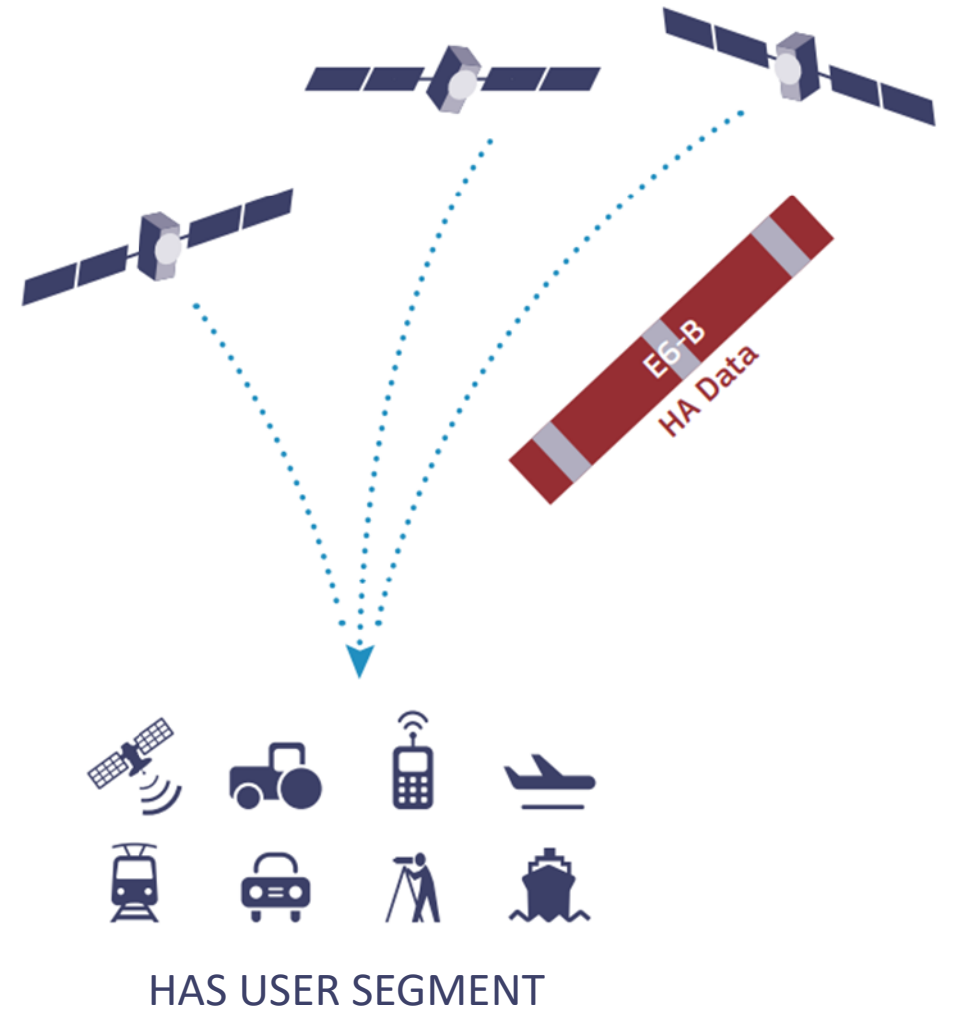
- Konkurrenz zu etablierten relativen Positionierungsmethoden wie RTK
- low-cost, low-quality, kinematic
- Kombination mit anderen...
 - Techniken: reverse PPP,...
 - Sensoren: accelerometer,...



Ausblick

PPP gewinnt an Bedeutung:

- Galileo HAS
- mehr Satelliten und Frequenzen
- Weiterentwicklungen von GNSS (z.B. LEO, Inter-Satellite-Links)
- sofortige Konvergenz?



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**Danke für Ihre
Aufmerksamkeit!**

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References

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- Aichinger-Rosenberger M, Wolf A, Senn C, Hohensinn R, Glaner MF, Moeller G, Soja B, Rothacher M (under review) MPG-NET: A low-cost, multi-purpose GNSS collocation station network for environmental monitoring