GNSS Feature Map Aided RTK Positioning in Urban Trenches

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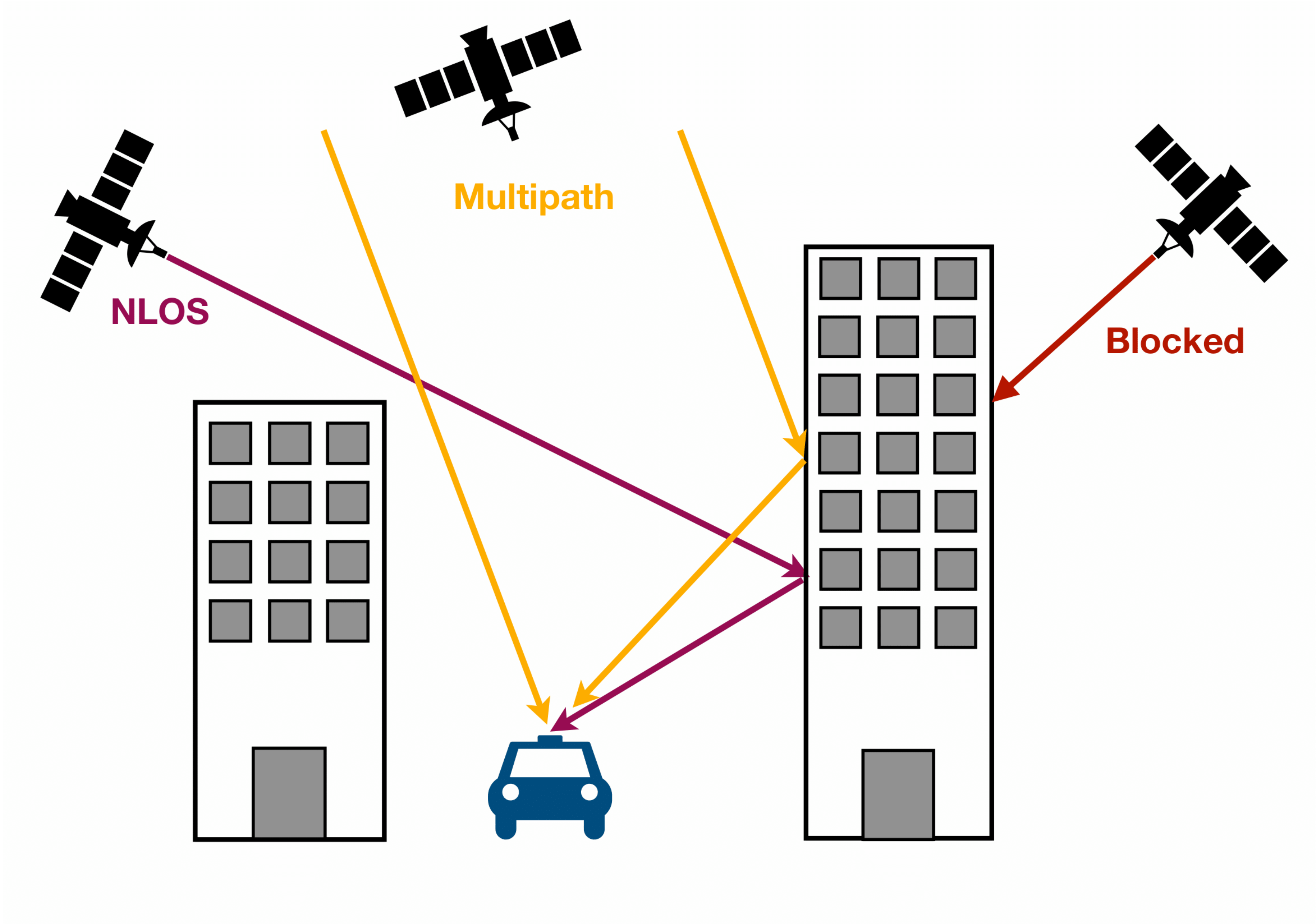
26th IEEE International Conference on Intelligent Transportation Systems
2nd iLoc Workshop - High-integrity Localization for Automated Vehicles

Motivation and Related Research

- Challenging GNSS signal propagation conditions in urban environments



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- Challenging GNSS signal propagation conditions in urban environments
- Multipath mitigation based on ground-track repeatability (e.g., *Fuhrmann et. al. 2014, Dong et. al. 2015*)

***T. Fuhrmann, X. Luo, A. Knöpfler, and M. Mayer**, „Generating statistically robust multipath stacking maps using congruent cells“, GPS Solutions, vol. 19, no. 1, pp. 83-92, 2014.*

***D. Dong, M. Wang, W. Chen, Z. Zeng, L., Song, Q. Zhang, M. Cai, Y., Cheng and J. Lv**, „Mitigation of multipath effect in GNSS short baseline positioning by the multipath hemispherical map“, Journal of Geodesy, vol. 90, no. 3, pp. 255-262, 2015.*

Motivation and Related Research

- Challenging GNSS signal propagation conditions in urban environments
- Multipath mitigation based on ground-track repeatability (e.g., *Fuhrmann et. al. 2014, Dong et. al. 2015*)
- 3DMA-GNSS (e.g., *Obst et. al. 2012, Peyraud et. al. 2013, Hsu et. al. 2015*)

***M. Obst, S. Bauer and G. Wanielik**, „Urban multipath detection and mitigation with dynamic 3D maps for reliable land vehicle localization“, in Proceedings of the 2012 IEEE/ION PLANS, pp. 685-691, 2012.*

***S. Peyraud, D. Bétaille, S. Renault, M. Ortiz, F. Mougel, D. Meizel and F. Peyret**, „About Non-Line-Of-Sight Satellite Detection and Exclusion in a 3D Map-Aided Localization Algorithm“, Sensors, vol. 13, no. 1, pp. 829-847, 2013.*

***L.-T. Hsu, Y. Gu and S. Kamijo**, „NLOS Correction/Exclusion for GNSS Measurement Using RAIM and City Building Models“, Sensors, vol. 15, no. 7, pp. 17329-17349, 2015.*

Motivation and Related Research

- Challenging GNSS signal propagation conditions in urban environments
- Representation of signal propagation-related features (*Ruwisch and Schön, 2022a*)
- Map information versus ray tracing (*Ruwisch and Schön, 2022b*)
- **Our contribution**: dynamic maps without city model information for carrier phase-based positioning

***F. Ruwisch and S. Schön**, „GNSS Feature Map: Representation of Signal Propagation-related Features in Urban Trenches“, in The International Technical Meeting of The Institute of Navigation, pp. 701-711, 2022.*

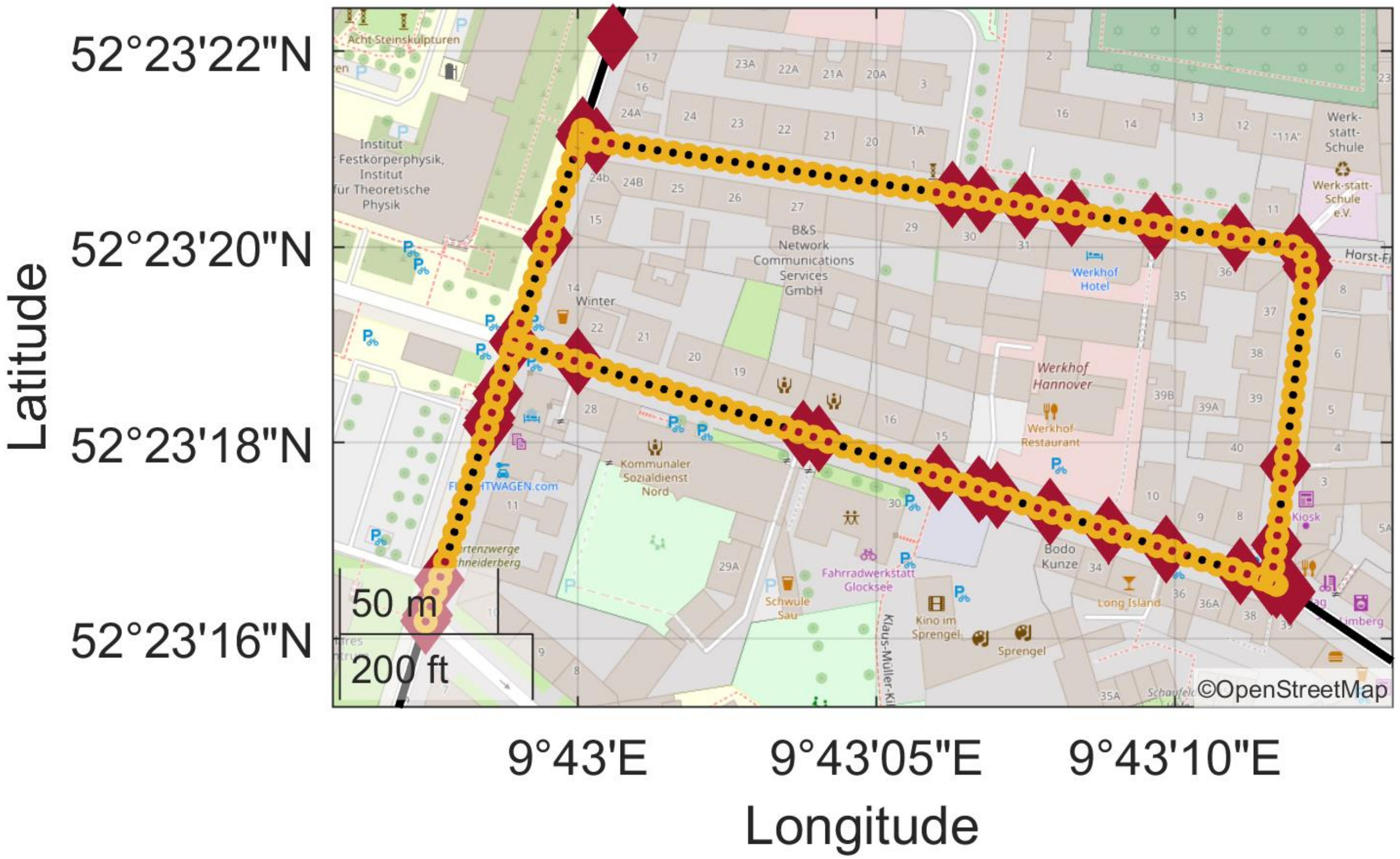
***F. Ruwisch and S. Schön**, „Performance Assessment of GNSS RTK Positioning in Urban Environments: Outlier Detection versus 3DMA-FDE“, in Proceedings of the 35th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+), pp. 2649-2663, 2022.*

Content

- GNSS Feature Map
- GNSS RTK positioning algorithm
- Performance evaluation
- Summary

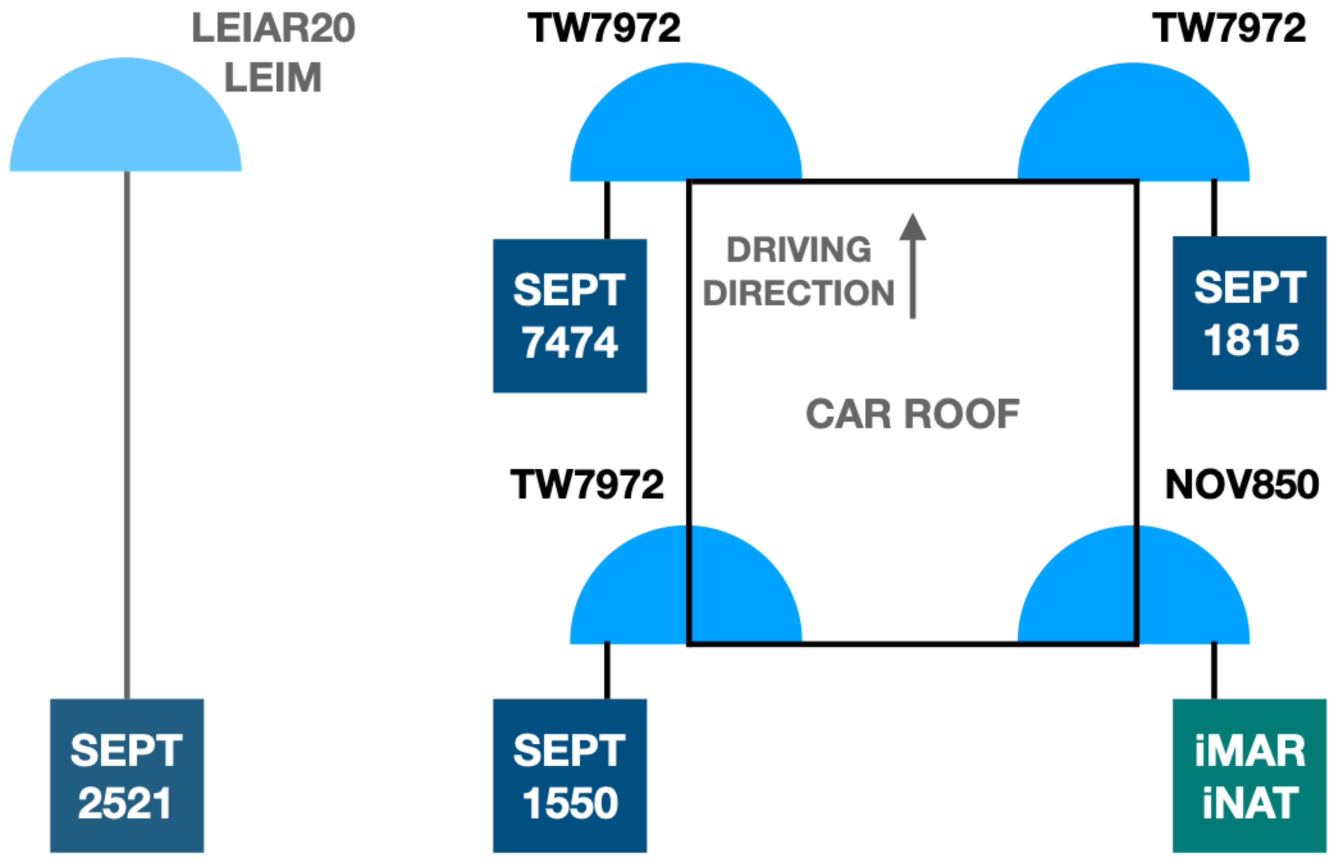
GNSS Feature Map - Generation

- Map generation based on OpenStreetMap
- Road model containing coordinates of the streets
- Interpolation into a regular point density

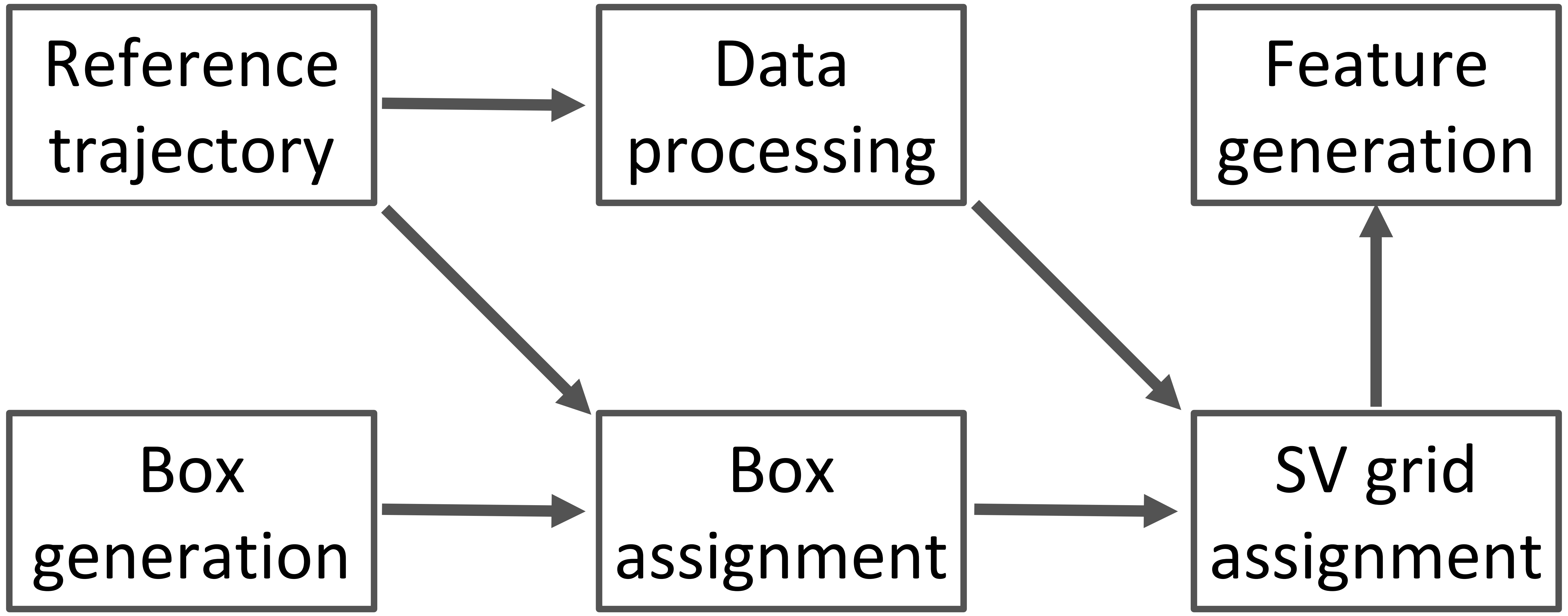


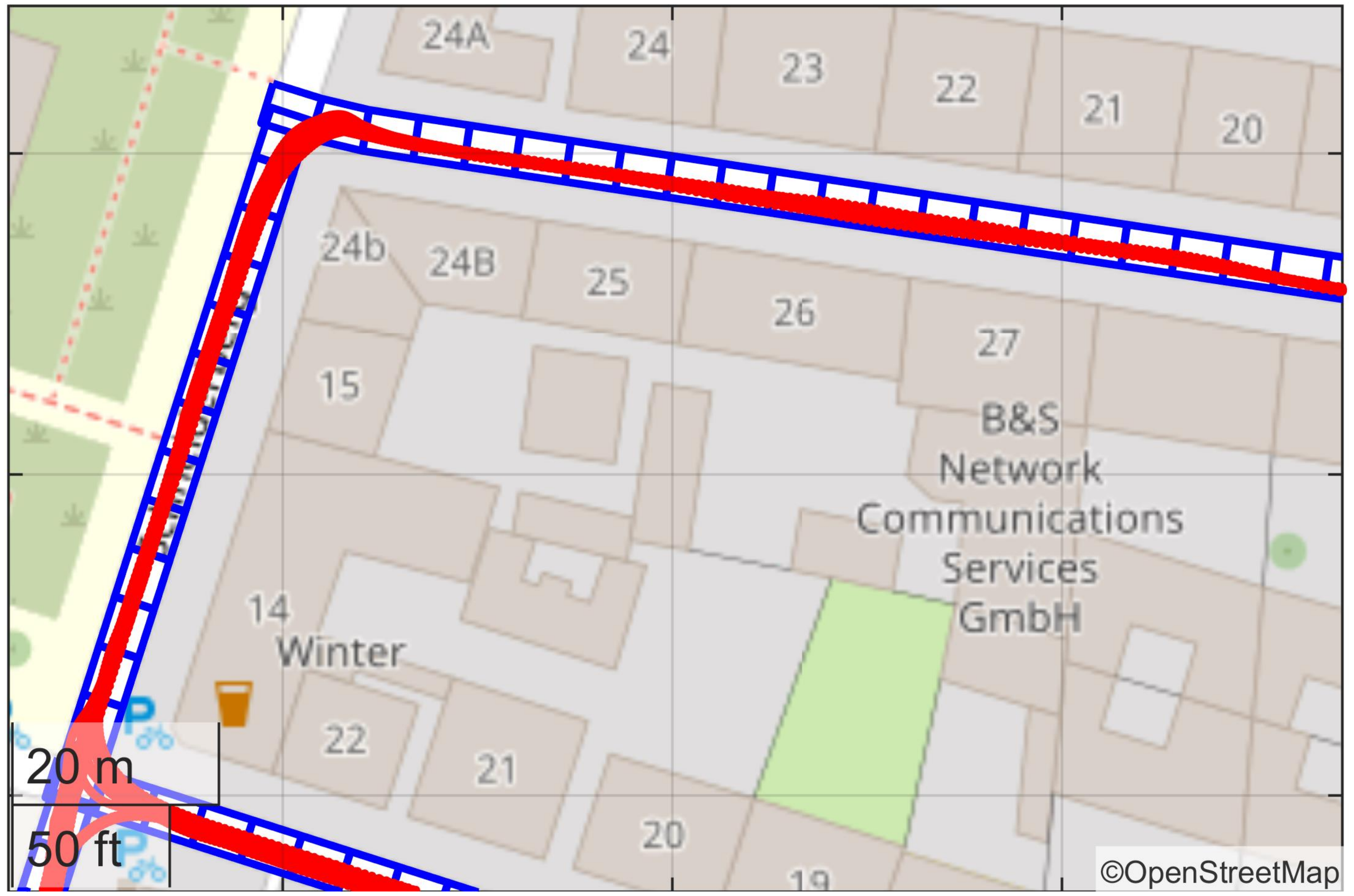
GNSS Feature Map - Experiment Setup

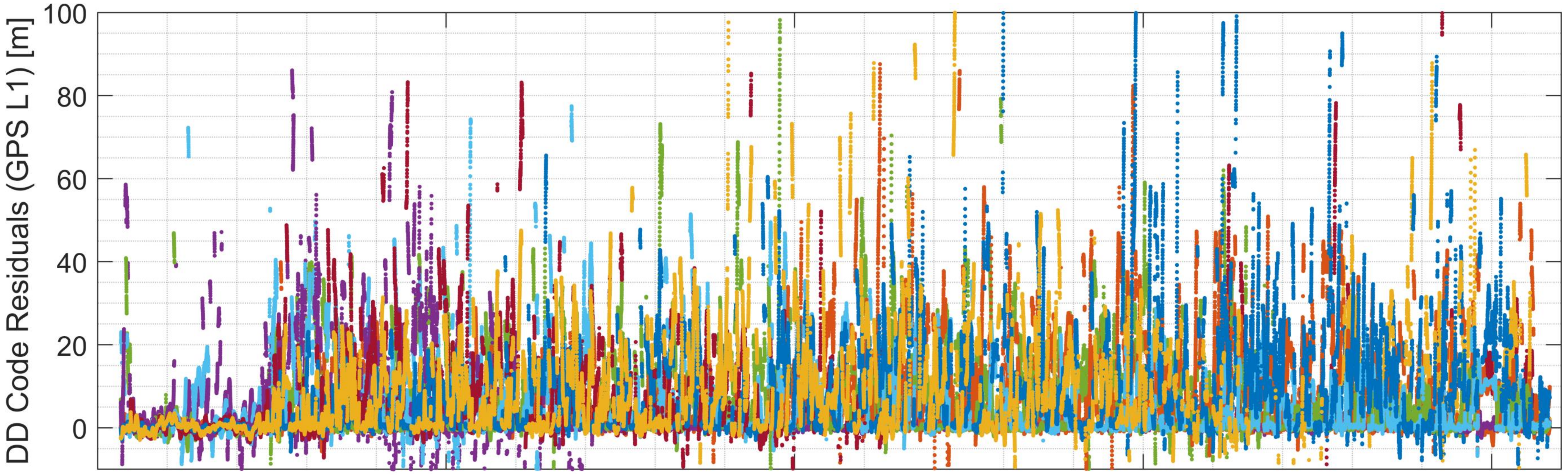
- Multi-GNSS, multi-frequency training data collection in 10 Hz
- Time span covers two days, total driving time of 5.5 h



GNSS Feature Map - Data Aggregation







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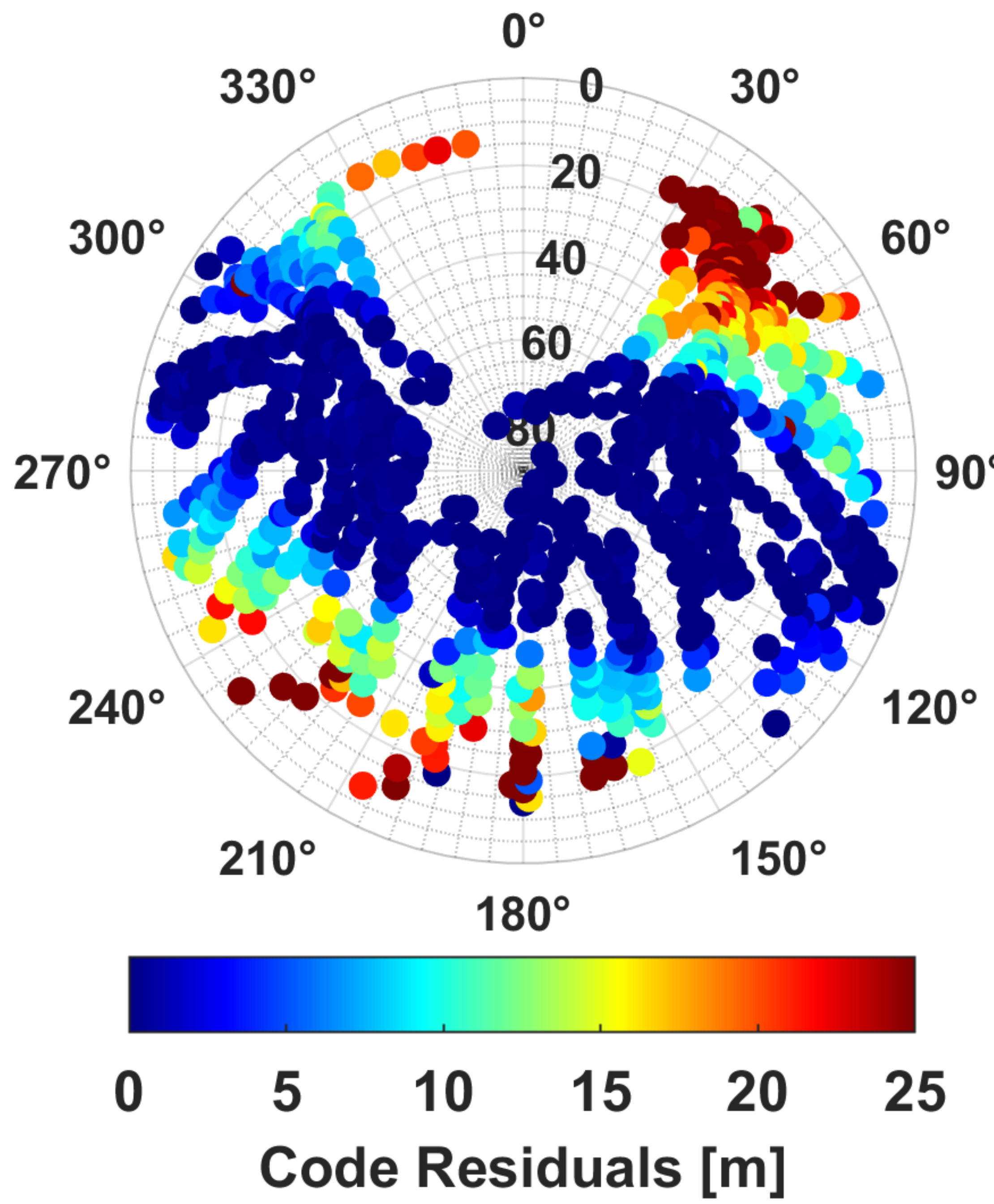

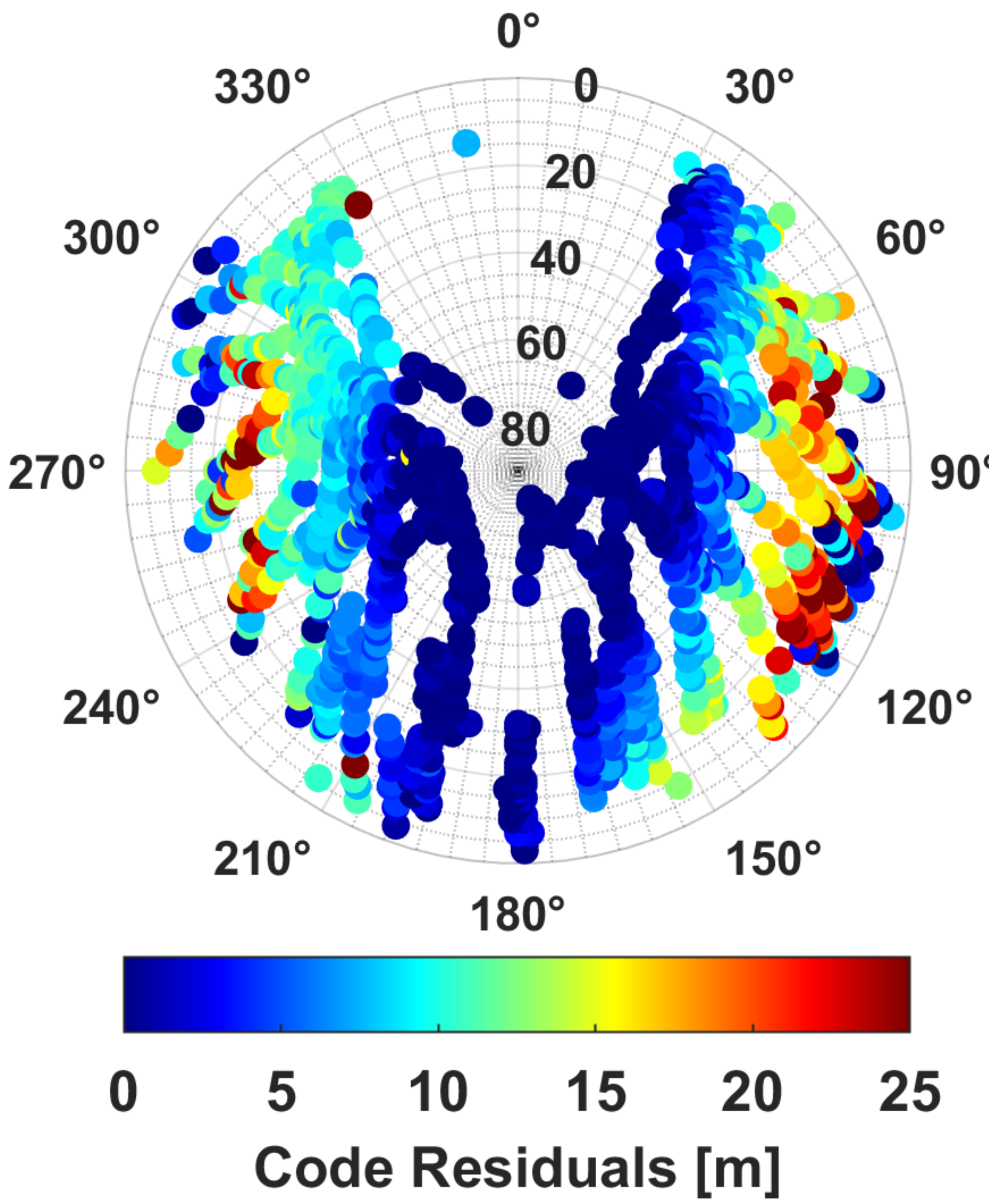

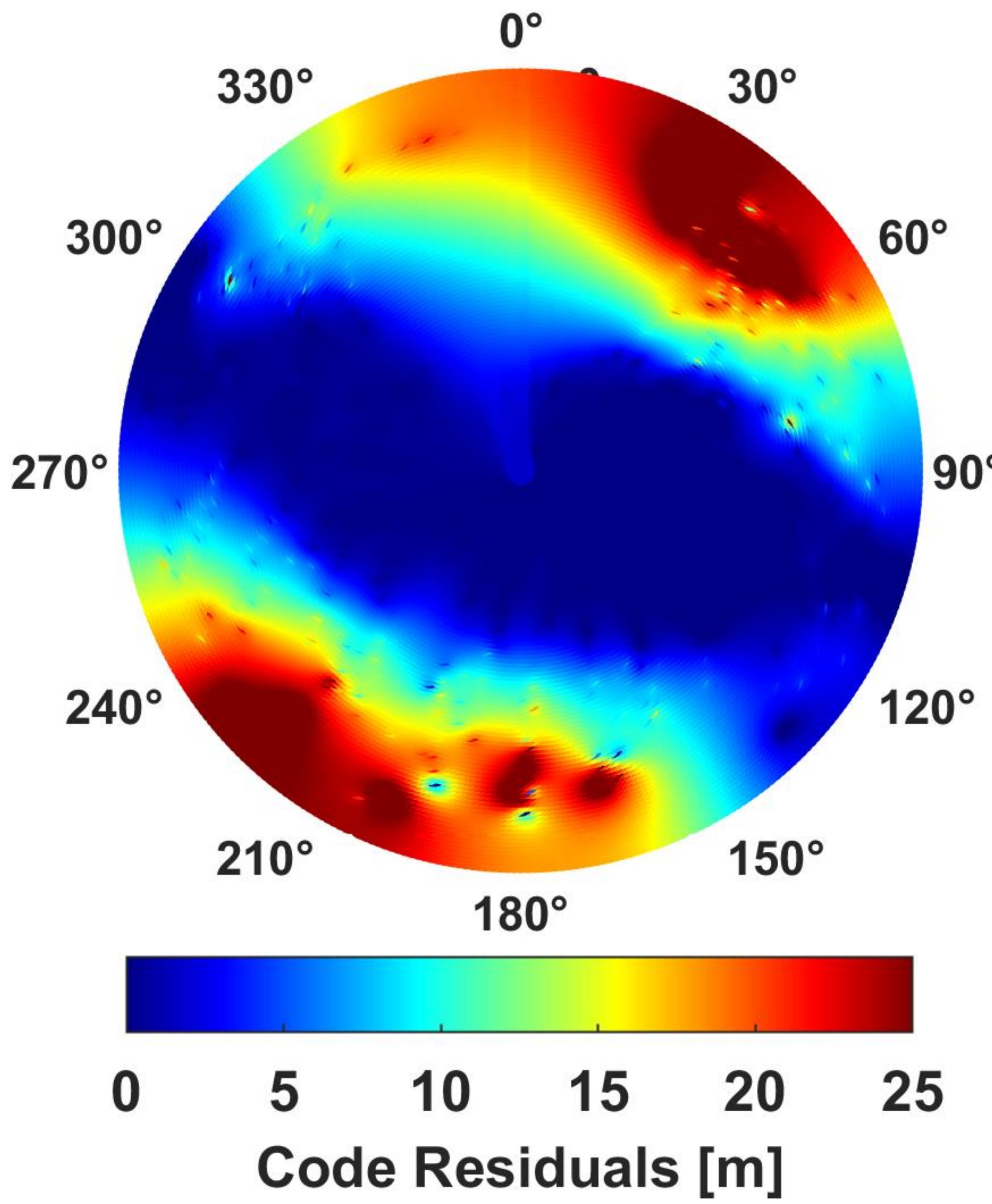

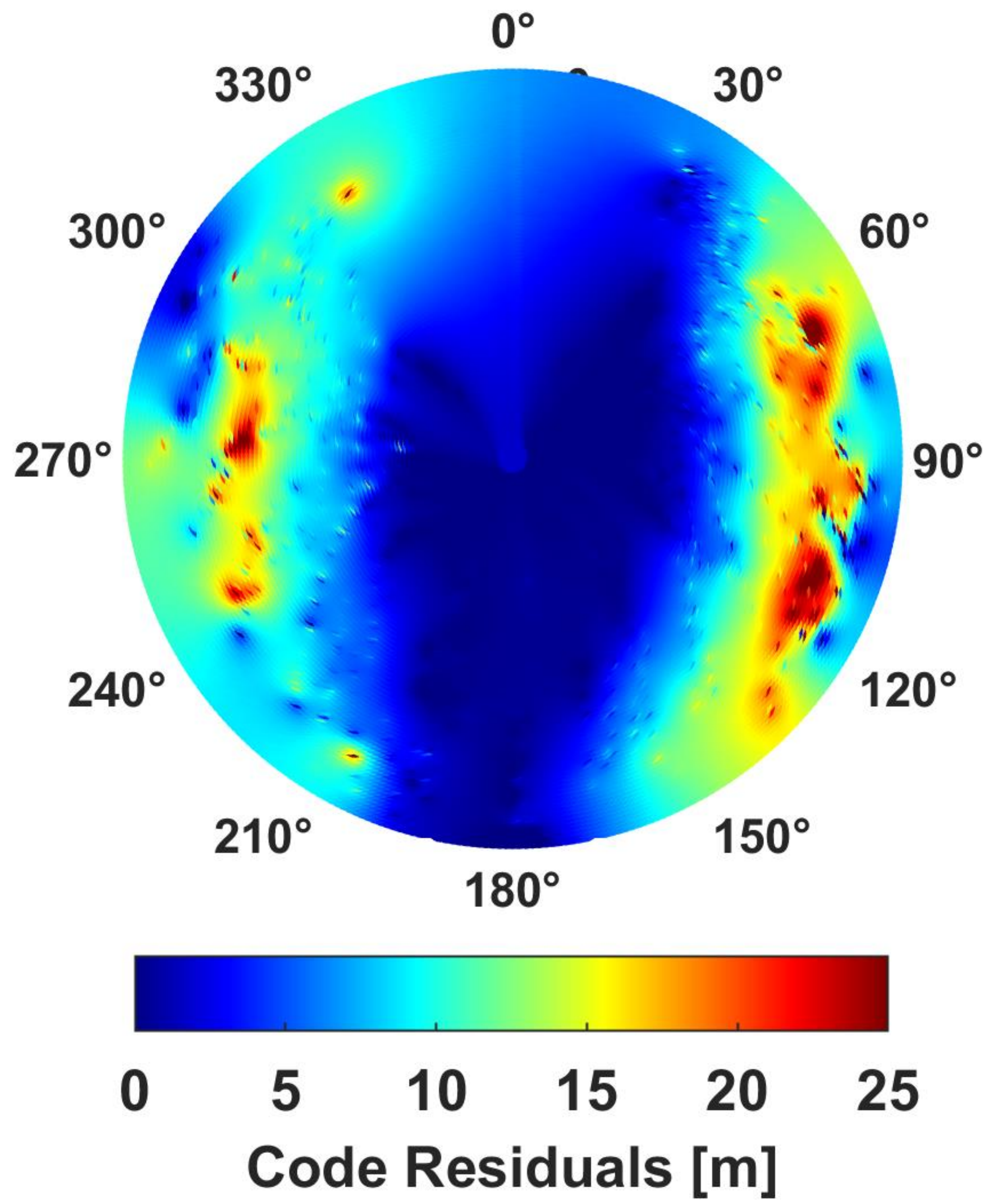

- Map consists of skyplots for each of the boxes
- Interpolation to guarantee full sky coverage

—> Final product is a GNSS Feature Map consisting of code residuals for all satellite positions at all boxes along the trajectory

GNSS RTK Positioning Algorithm

- Multi-GNSS, multi-frequency RTK positioning algorithm in an Extended Kalman filter
- Observations:

$$\mathbf{l}_k = \left[\Phi_{rb}^G, \Phi_{rb}^R, \Phi_{rb}^E, \Phi_{rb}^C, \rho_{rb}^G, \rho_{rb}^R, \rho_{rb}^E, \rho_{rb}^C\right]^T$$

- State vector:

$$\mathbf{x} = \left[x_r, y_r, z_r, \mathbf{N}_{rb}^G, \mathbf{N}_{rb}^R, \mathbf{N}_{rb}^E, \mathbf{N}_{rb}^C\right]^T$$

- EKF formulation:

$$\mathbf{K}_k = \mathbf{Q}_{x,k}^- \mathbf{H}_k^T \left(\mathbf{H}_k \mathbf{Q}_{x,k}^- \mathbf{H}_k^T + \mathbf{Q}_{l,k}\right)^{-1},$$

$$\mathbf{Q}_{x,k}^+ = \left(\mathbf{I} - \mathbf{K}_k \mathbf{H}_k\right) \mathbf{Q}_{x,k}^- \left(\mathbf{I} - \mathbf{K}_k \mathbf{H}_k\right)^T + \mathbf{K}_k \mathbf{Q}_{l,k} \mathbf{K}_k^T,$$

$$\mathbf{x}_k^+ = \mathbf{x}_k^- + \mathbf{K}_k \left(\mathbf{l}_k - \mathbf{H}_k \cdot \mathbf{x}_k^-\right).$$

GNSS RTK Positioning Algorithm

Algorithm 1 GNSS Feature Map Integration

for every epoch **do**
- EKF time update
- Calculate satellite positions
- **if** Predicted position is inside any box polygon **then**
  - Retrieve GNSS Feature Map information
  - **if** any FM code residual > 3 m **then**
    - Adapt weight
- EKF measurement update

$$\sigma_{\Phi,\mathrm{FM}} = \begin{cases} \sigma_{\Phi}, & \left|v^{\mathrm{FM}}\right| \leq 3 \\ \sigma_{\Phi} \cdot \frac{\left|v^{\mathrm{FM}}\right|}{\sigma_{\rho_0}}, & \left|v^{\mathrm{FM}}\right| > 3 \end{cases}$$

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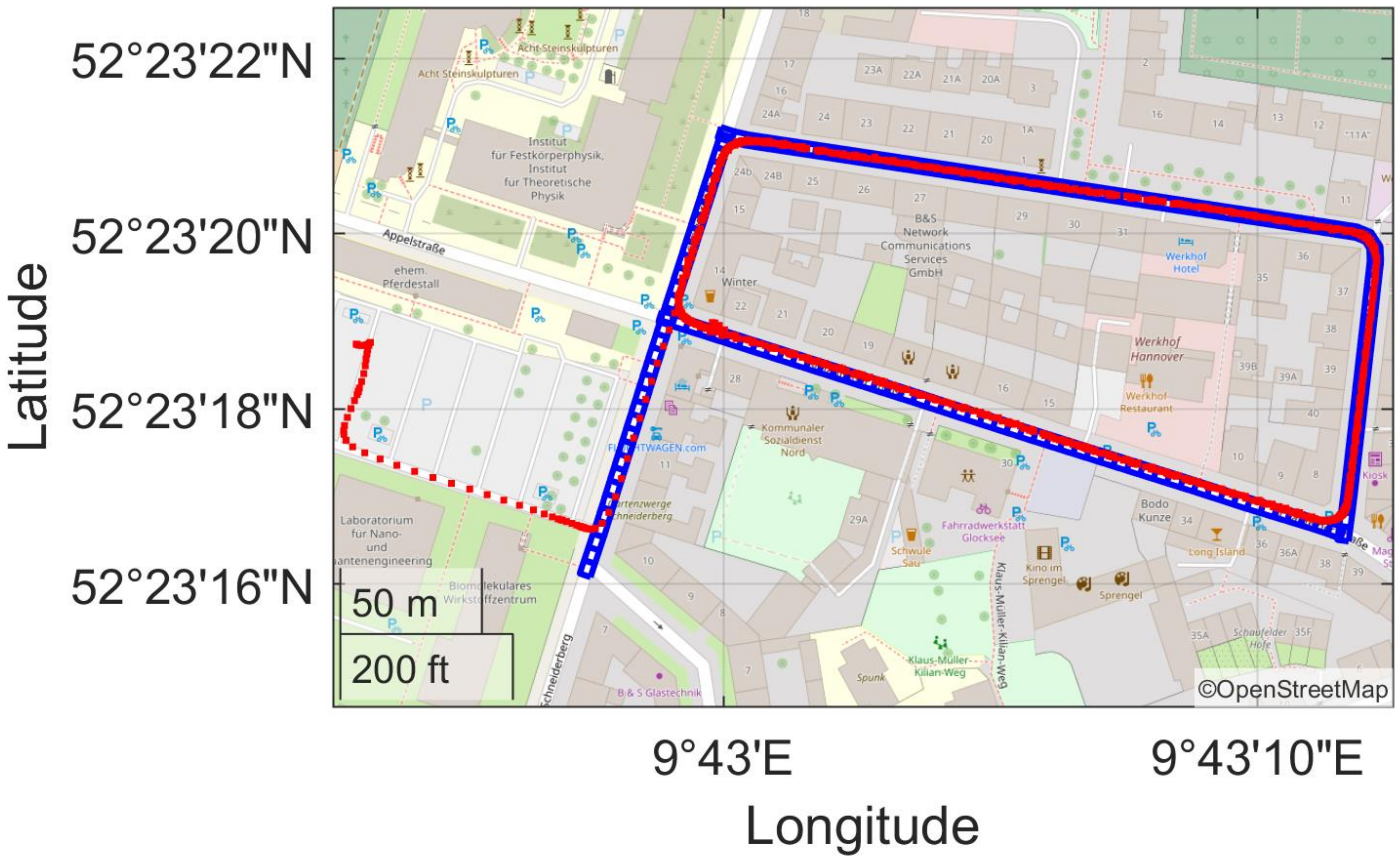
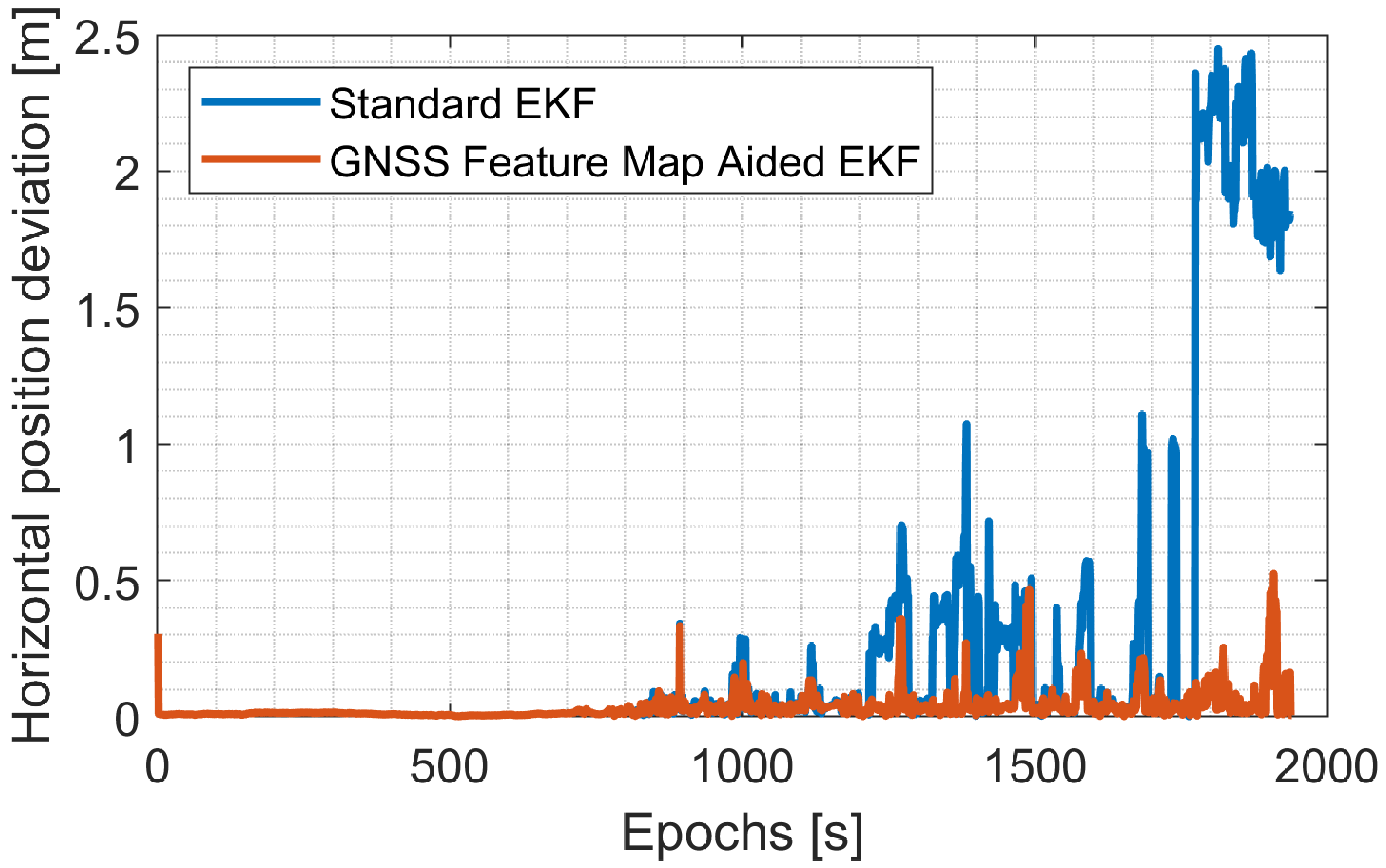
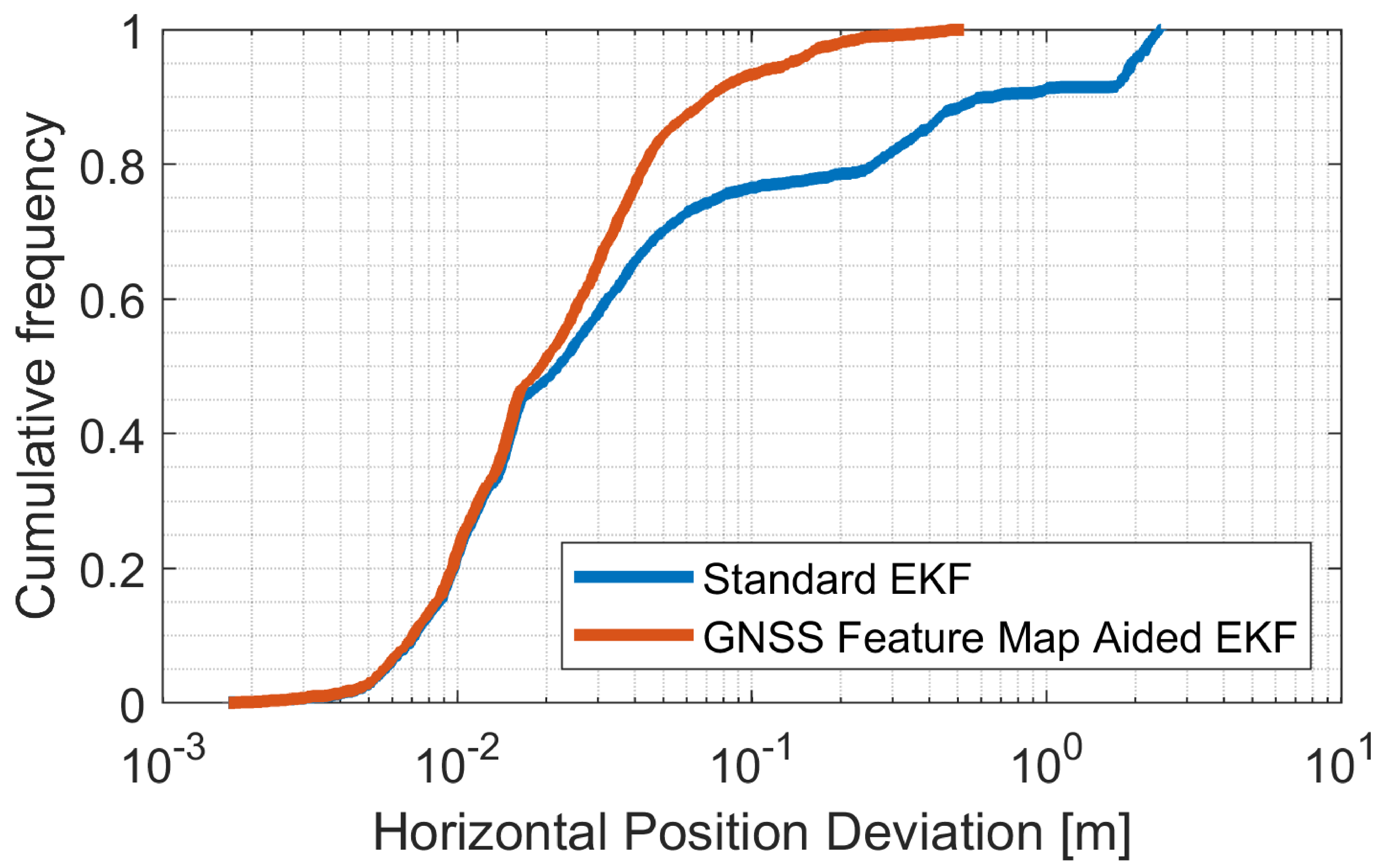
Performance Evaluation

- Multi-GNSS, multi-frequency test data collection
- Measurement campaign independent from training data set
- Same equipment as in the training data
- Around 30 minutes (starting with static open sky followed by 10 rounds through the urban trench)



Performance Evaluation - Accuracy

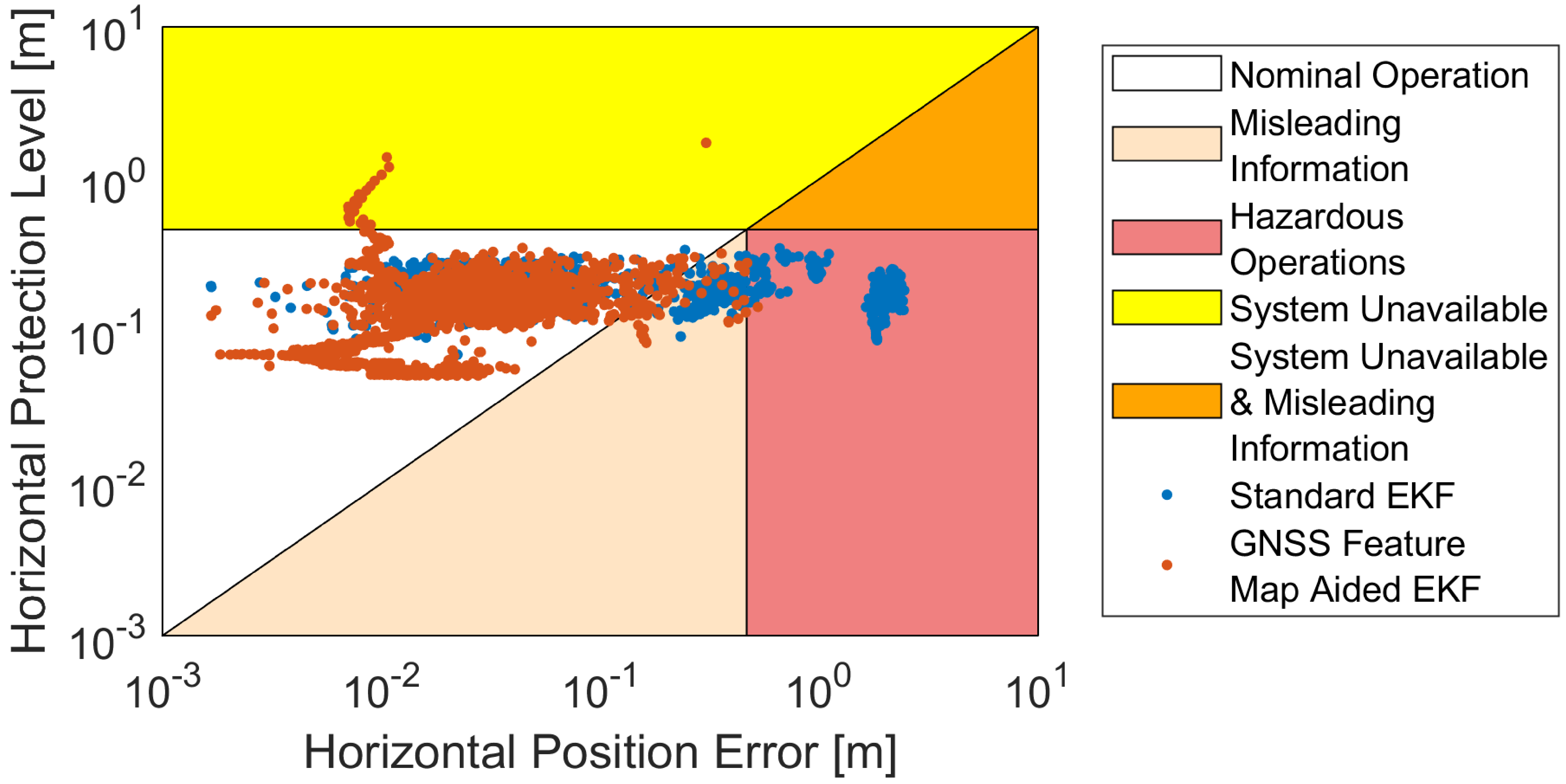




	RMS	Max. Error
Standard EKF	0.63 m	2.45 m
FMA EKF	0.06 m	0.52 m
Improvement	90.5 %	78.8 %

	Standard EKF	FMA EKF
50 %	< 0.02 m	< 0.02 m
95 %	< 1.95 m	< 0.13 m
99 %	< 2.32 m	< 0.27 m

Performance Evaluation - Integrity



- Relation between position error, protection level and alert limit visualized in Stanford diagram
- Proposed approach shifts the solution from right to left

	NO	MI	HO	SU	SU & MI
Standard EKF	77.4 %	9.3 %	12.0 %	1.2 %	0 %
FMA EKF	95.8 %	2.8 %	0.1 %	1.2 %	0 %

Summary

- GNSS Feature Map containing information on code residuals for all satellite positions in a regular grid along a selected trajectory based on real data experiments
- Integration in an EKF for GNSS RTK positioning by down-weighting potentially faulty satellites without external city model information
- RMS of horizontal position deviations is improved by 90.5 % and the maximum error is reduced from 2.45 m to 0.52 m
- Increased accuracy leads to more NO modes (95.8 % compared to 77.4 %, MI and HO epochs are minimized)

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

Acknowledgements

The results were obtained in the project KOMET, which is managed by TÜV-Rheinland (PT-TÜV) under the grant 19A20002C and is funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), based on a resolution of the German Bundestag.