The Joint Research Project SIMULTAN
WP3.1: GNSS Campaigns and Research

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Urban GNSS Sites and Campaign Design

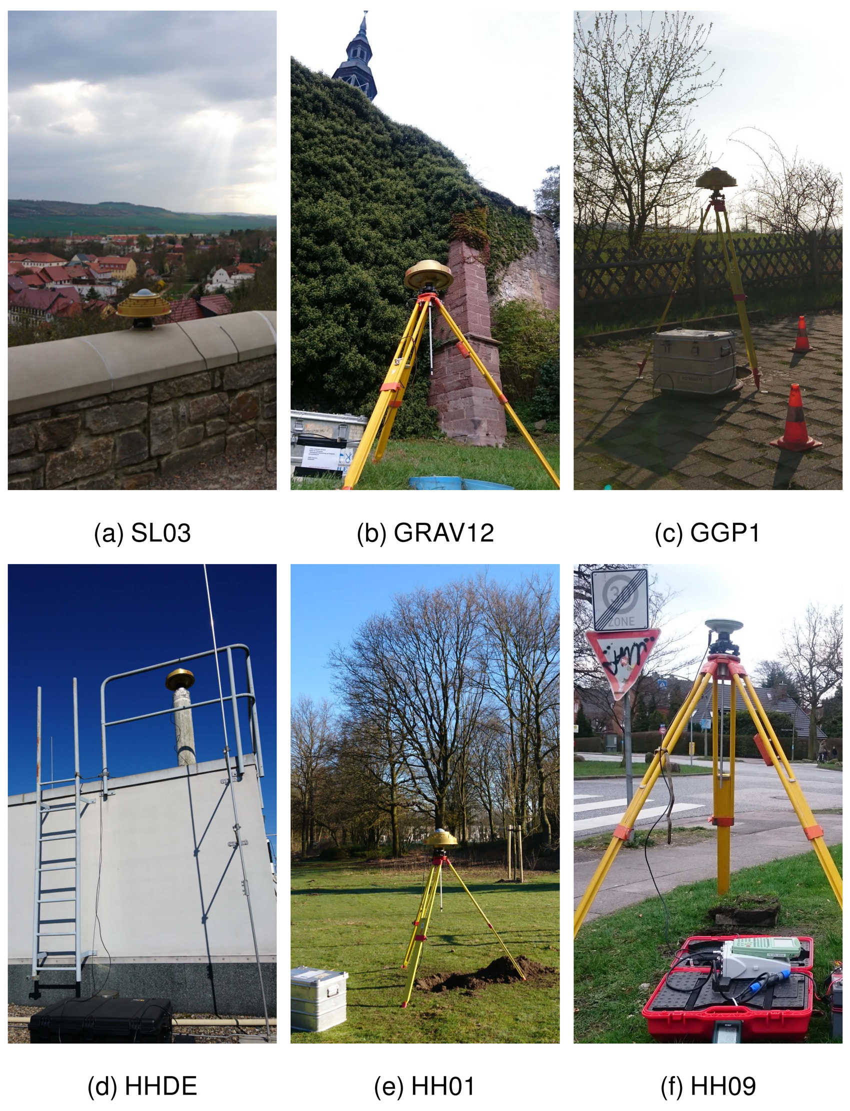

Figure 1: Co-located urban GNSS sites as part of geo-monitoring networks to control and observe subsidence processes, (a-c) Bad Frankenhausen (Thuringia), (d-f) Hamburg Groß-Flottbek.

SIMULTAN-Project

- Sinkhole Instability, MULTiscale monitoring and ANalysis: gain a deeper understanding of the complex processes, interactions and characteristics of the underground and the surface interaction in urban environments, [Kersten et al., 2017a].

GNSS-Campaign Design in SIMULTAN

- Multi-GNSS equipment (Leica GRX1200+GNSS, Novatel 703GGG, Leica AR25.R3) with height adaptor FG ANA 100B for precise height determination.
- Four hour sessions, at least 3 independent repetitions per site.
- Data recording (1 Hz) at co-located sites (GNSS, levelling, gravimetry).
- Star-like GNSS monitoring network, fixed in local reference stations.

Urban GNSS Sites

- Urban infrastructure yields to variable and high multipath as well as challenging satellite geometry at each co-located site.
- Short baselines of approx. 700-1800 m.

Bad Frankenhausen - Network

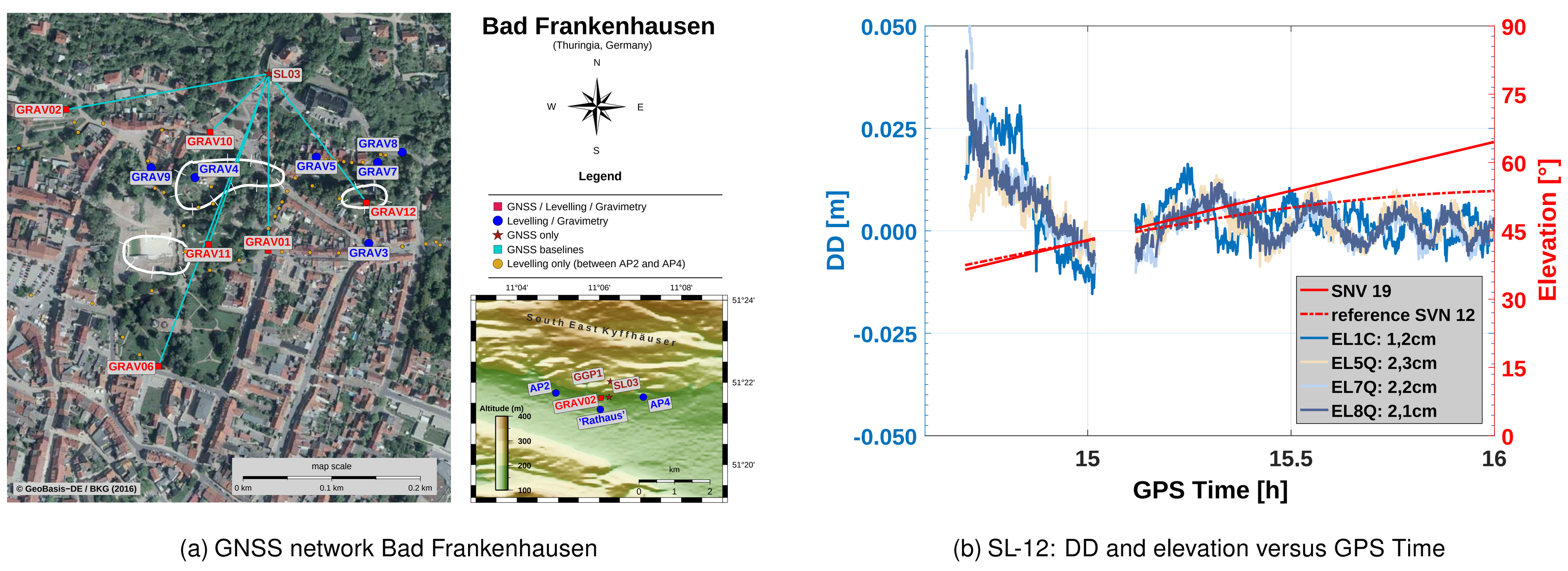

Figure 2: Analysis of Galileo GNSS sites, (a) network with indicated baseline, (b) double difference residuals for four hour session captured at GRAV12 (cf. Fig. 1b).

- **SL03:** Local reference station (stability check by SA*POS*® stations Erfurt (0209), Buttstädt (0221), Sondershausen (0200), Mühlhausen (0214)).
- **GRAV12:** Co-located point in close vicinity to a concrete wall (located in the north of the GNSS site), challenging obstruction geometry present.
- **Baseline SL03-GRAV12 (SL-12)**: 190 m, significant impact of multipath detectable.
- Multipath signatures detectable (sinusoidal) with frequencies of ≈20 minutes that lead to amplitudes in Galileo DDs (E5a, E5b and AltBOC E5a+b) although low noise is present. Highest noise on Galileo E1 signal detected, [Ruwisch et al., 2016].

Hamburg - Network

- **HHDE:** Local reference station at DESY (Deutsches Elektronen-Synchrotron), stability check by SA*POS*® stations (Lower Saxony) Buchholz (0680), Stade2 (1662), Lüneburg (0660).
- **HH01:** Co-located site in a park with several trees which reduces satellite visibility at low elevations.
- **HH08:** Site with close vicinity of a concrete wall, signals distorted by discounter market in north/east and several high trees in the south. Additionally, frequent traffic of trucks leads to signal interruptions.
- Challenging satellite visibility at several GNSS stations.

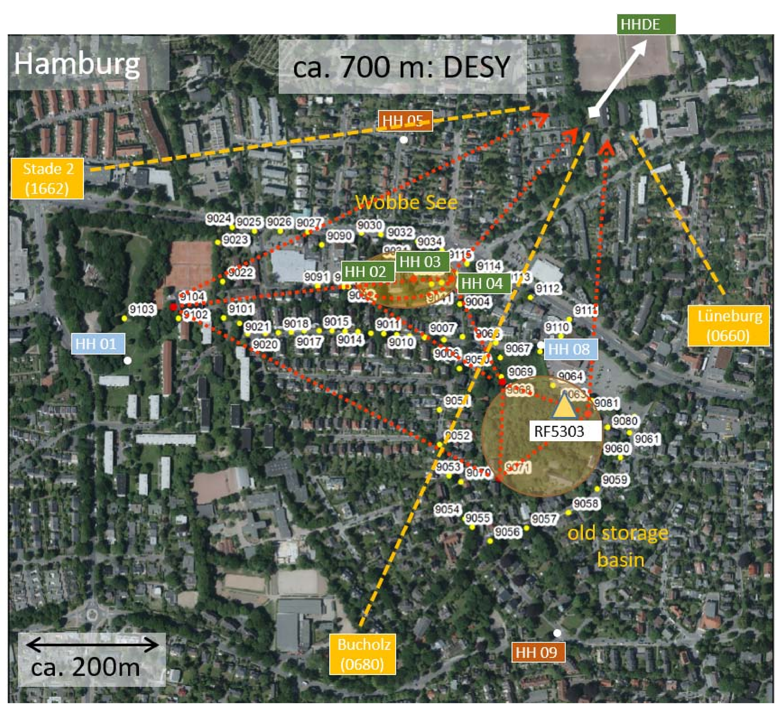

Figure 3: Combined geophysical network in Hamburg, Groß-Flottbek.

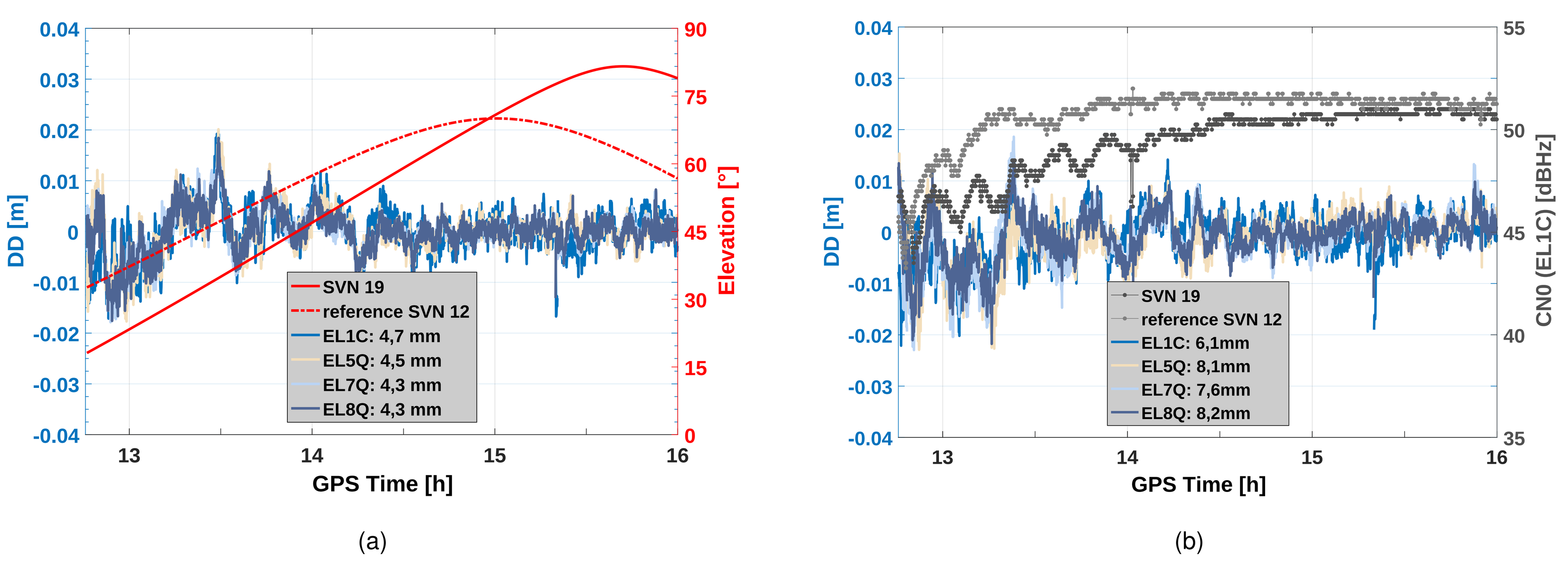

Figure 4: Galileo DD with individual standard deviation, shown here for selected baselines, (a) DE-01: DD and elevation versus GPS Time, (b) DE-08: DD and C/N_0 values versus GPS Time.

Details Hamburg

Studies of urban GNSS double differences show (cf. Fig. 3):

- **Baseline HHDE-HH01 (DE-01)**: 1.050 m, optimal results obtainable due to moderate obstructions.
- **Baseline HHDE-HH08 (DE-08)**: 830 m, frequently changing site geometry and challenging obstruction situation lead to significant noise in studied Galileo DD.

HH01 - Residuals of DD individual signals close similar to each other.

- Challenging geometry for optimal GNSS satellite tracking at urban GNSS sites.

HH08 - Residuals of DD show higher magnitudes.

- E1 indicates higher noise than other Galileo signals (ca. 80% below 2 mm), [Kersten und Schön, 2017].
- Modified Allan standard deviation results to averaging time of 20 sec (linear).
- Signal of E1 (EL1C) corresponds to gradient of -1 (Flicker Phase Modulation (FPM)): DD superimposed by atmospheric delays as well as site specific multipath geometry (static and dynamic).

Stability of Local Reference Stations

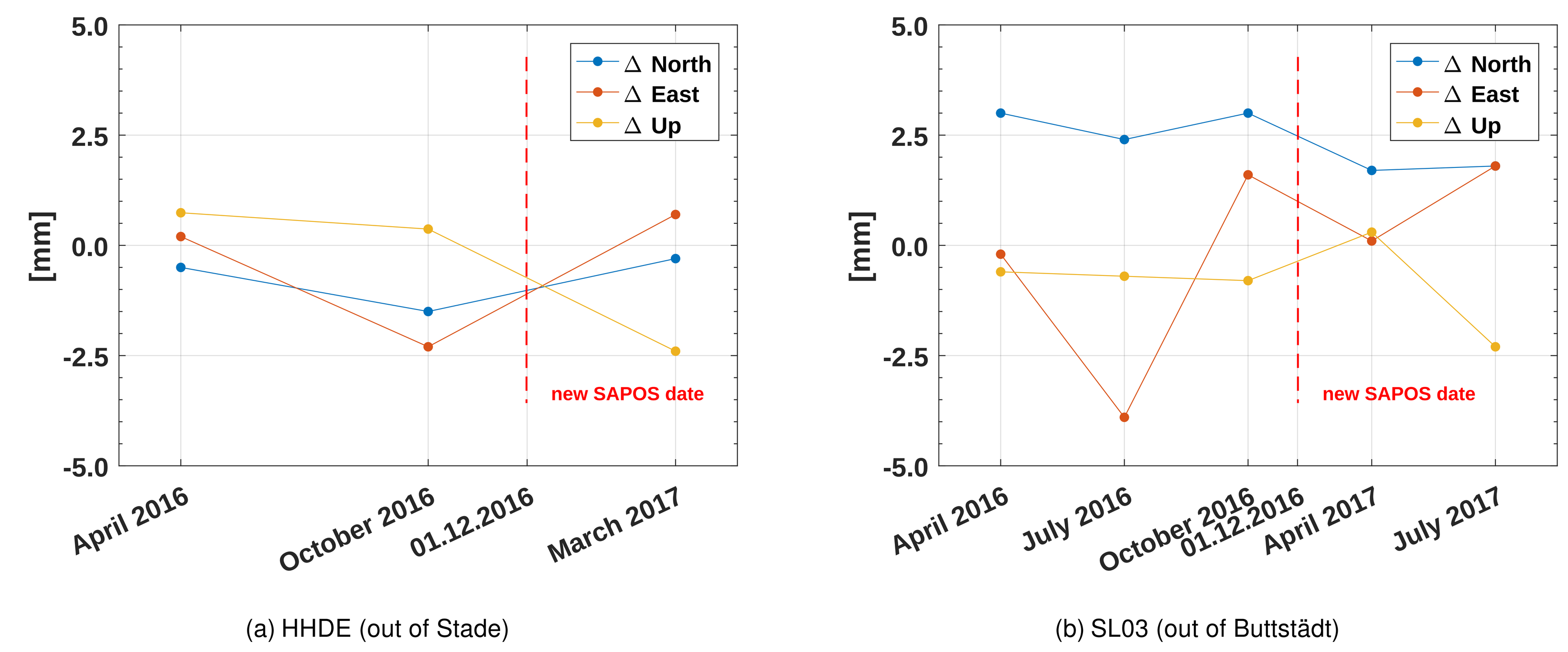

Figure 5: Comparisons of Epochs to test the stability of local reference stations, (a) local station HHDE in Hamburg (project HHX), (b) local station SL03 in Bad Frankenhausen (project BFH).

Evaluation and Findings

- L3 (ionosphere free) linear combination with noise of 6 mm used for fixing HHDE and SL03 via SA*POS*®
- Local references are stable; during campaigns no displacements are detected.
- Longer time series importent to separate observations from superimposed noise (semi-annual signals, hydrology, etc.).
- Common Geodetic Datum by SA*POS*® (ETRS89) and new Datum provides improved consistency between physical (DHHN2016) and mathematical (ellipsoidal) heights; important for integration.
- New SA*POS*® Datum introduces heights differences of up to 20 mm in coordinates but improved consistency of GNSS ellipsoidal and physical DHHN2016-heights (gravity field, geoid).

Conclusions and Further Steps

- Study of Galileo observations in challenging, urban environments by [Ruwisch et al., 2016].
- Challenging satellite geometry improved by applying adaptive dynamic elevation masks (dynMsk) studied by [Icking et al., 2016].
- Campaigns finished and processing of epoch comparisons ongoing; solutions published frequently, [Kersten und Schön, 2017, Kersten et al., 2017b].
- Data provided through WebDAV server for both projects (HHX and BFH) for dedicated WP partners.

Further steps

- Development and evaluation of integrated model for levelling and gravimetric data sets, [Kersten et al., 2017a, Weise et al., 2017].
- Quantification and separation of superimposed signals as e.g. hydrological, atmospheric, seasonal variations and tidal effects.
- Studies and application of GNSS low-cost reference stations in combination with urban infrastructure as street furniture like, e.g. streetlamps etc., [Kröger et al., 2017].

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