Galileo for GNSS-Monitoring Networks in Urban Environments

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Motivation | Galileo for Inner City GNSS Sites?

Facts

- Densification of Galileo constellation (cf. Tab. 1).
- New GNSS signals E5a, E5b & E5a+b (EL5Q, EL7Q, EL8Q) provide improved reliability with respect to environmental influences and possibly allow better separation between noise, observation and distortions.
- More satellites in new constellations possibly optimize GNSS networks at challenging sites.

Questions

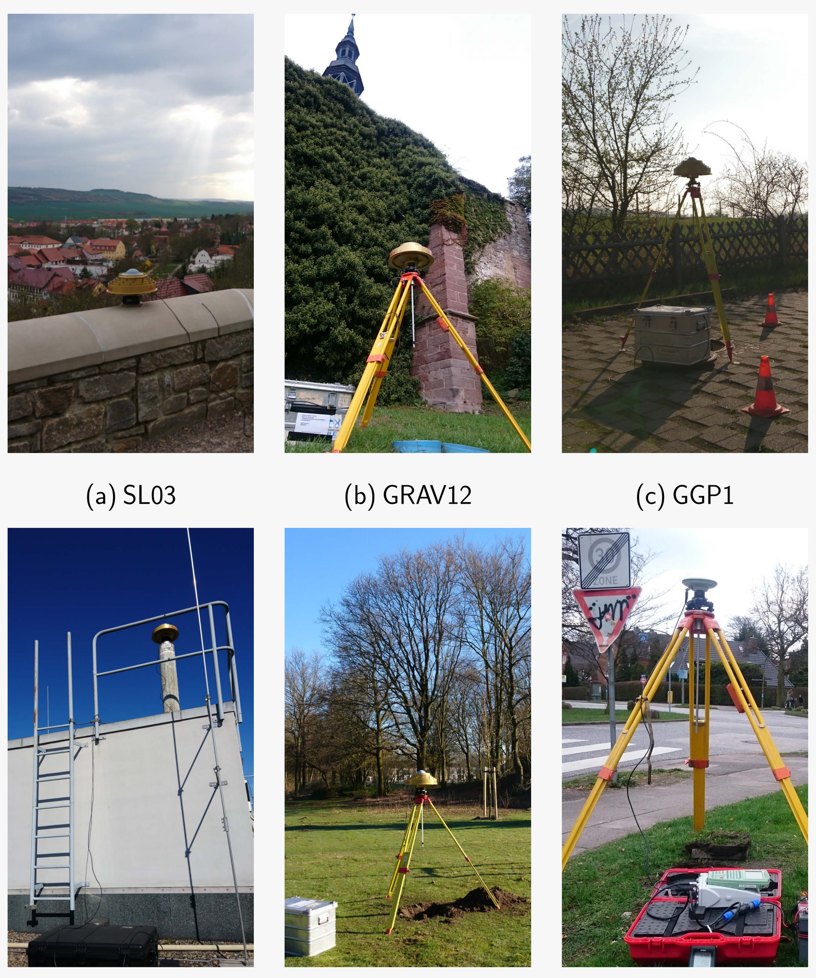
- What kind and amount of noise can be expected in GNSS double difference (DD) residuals at urban GNSS sites?
- Are multipath structures on Galileo carrier phase observations comparable with respect to traditional systems like, e.g., GPS/GLONASS?
- Any elevation dependent structures or effects on Galileo DD residuals?

Status	Satellite Name	SV-ID	Orbit Slot	Clock
useable	GSAT0101	11	B05	RAFS[1]
	GSAT0102	12	B06	PHM[2]
	GSAT0103	19	C04	PHM[2]
	GSAT0203	26	B08	PHM[2]
	GSAT0204	22	B03	RAFS[1]
	GSAT0205	24	A08	PHM[2]
	GSAT0206	30	A05	PHM[2]
	GSAT0208	08	C07	PHM[2]
	GSAT0209	09	C02	PHM[2]
	GSAT0210	01	A02	PHM[2]
	GSAT0211	02	A06	PHM[2]
under test	GSAT0201	18	Ext01	PHM[2]
	GSAT0202	14	Ext02	PHM[2]
under commission	GSAT0207	07	C06	
	GSAT0212	03	C08	
	GSAT0213	04	C03	
	GSAT0214	05	C01	
not available	GSAT0104	20	C05	RAFS[1]

[1]RAFS: Rubidium Atomic Frequency Standard, [2]PHM: Passive Hydrogen Maser

Table 1: Galileo constellation by April 24th, 2017, source: ESA.

Urban GNSS Sites and Campaign Design



(a) SL03 (b) GRAV12 (c) GGP1
(d) HHDE (e) HH01 (f) HH09

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

- Sinkole Instability, MULTiscale monitoring an ANalysis: gain a deeper understanding of the complex processes, interactions and characteristics of the underground and the surface interaction in urban environments.

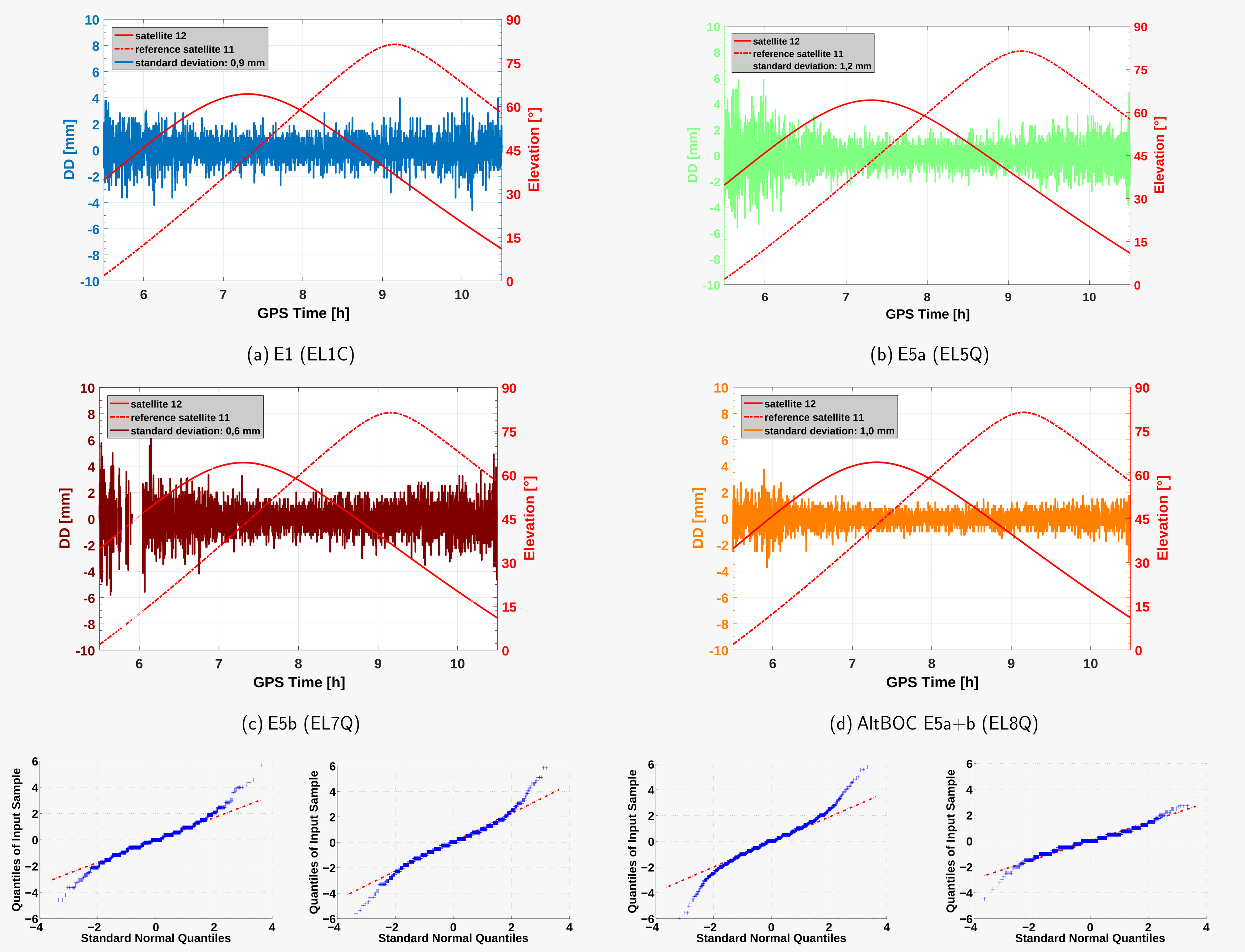
GNSS-Campaign Design in SIMULTAN

- Multi-GNSS equipment (Leica GRX1200+GNSS, Novatel 702GGG, Leica AR25.R3).
- Height adaptor FG ANA 100B for precise height determination at GNSS sites.
- Four hour sessions, at least independent 3 repetitions per site.
- Data recording (1 Hz) at co-located sites (GNSS, levelling, gravimetry).

Urban GNSS Sites

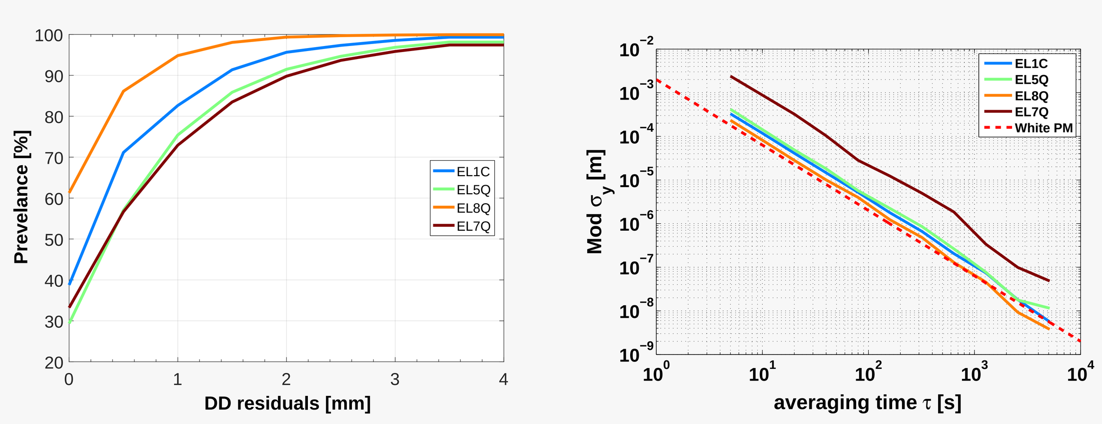
- Urban infrastructure supports variable and high multipath as well as challenging satellite geometry at each co-located site.
- Short baselines of approx. 700-1800 m.

Zero Baseline | Laboratory Network



(a) E1 (EL1C) (b) E5a (EL5Q) (c) E5b (EL7Q) (d) AltBOC E5a+b (EL8Q)
(e) E1 (EL1C) (f) E5a (EL5Q) (g) E5b (EL7Q) (h) E5a+b (EL8Q)

Figure 2: Galileo double differences (DD) and quality measures, (a-d) Galileo DD for individual signals, (e-h) Qantile-Quantile (Q-Q) plots.



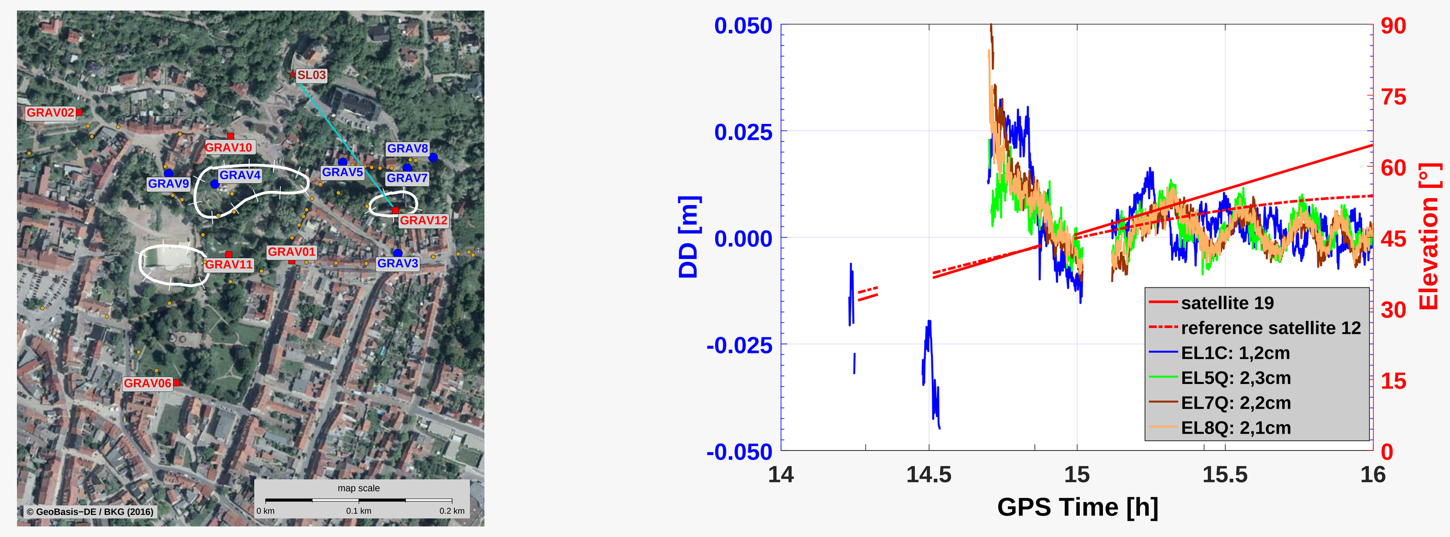
(a) (b)

Figure 3: Statistics for noise in Galileo DD, (a) cumulative histogram, (b) modified Allan standard deviation.

Findings

- Q-Q plots: normal distribution and some outliers
- White PM $\tau^{-3/2}$ for averaging time of 10^3 sec (15 minutes)
- few elevation dependency, highest noise for E5b (EL7Q) expected

Short Baseline | Bad Frankenhausen



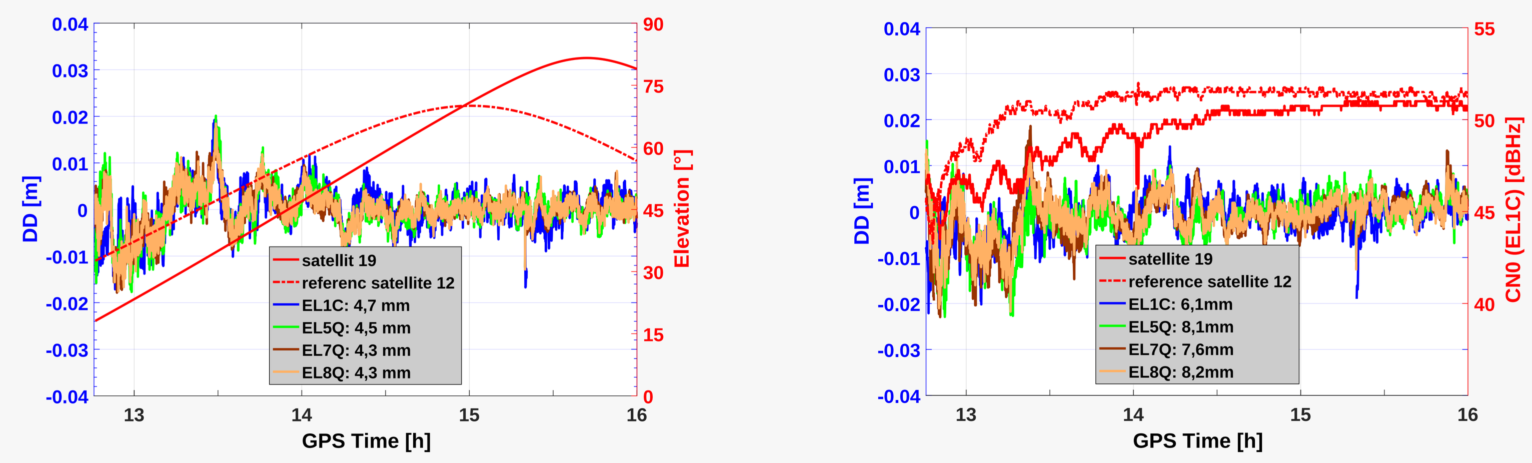
(a) GNSS network Bad Frankenhausen (b) SL-12: DD and elevation versus GPS Time

Figure 4: 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, Buttstädt, Sondershausen, Mühlhausen).
- **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 present (cf. Fig. 4b). Highest noise on Galileo E1 signal detected.

Short Baseline | Hamburg

- **HHDE:** Local reference station at DESY (Deutsches Elektronen-Synchrotron), stability check by SA*POS*® stations (Lower Saxony) Buchholz, Stade2, Lüneburg.
- **HH01:** Co-located site at sub-terrain in a park with several trees which reduce satellites 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 lead to signal interruptions.
- **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.



(a) DE-01: DD and elevation versus GPS Time (b) DE-08: DD and C/N_0 values versus GPS Time

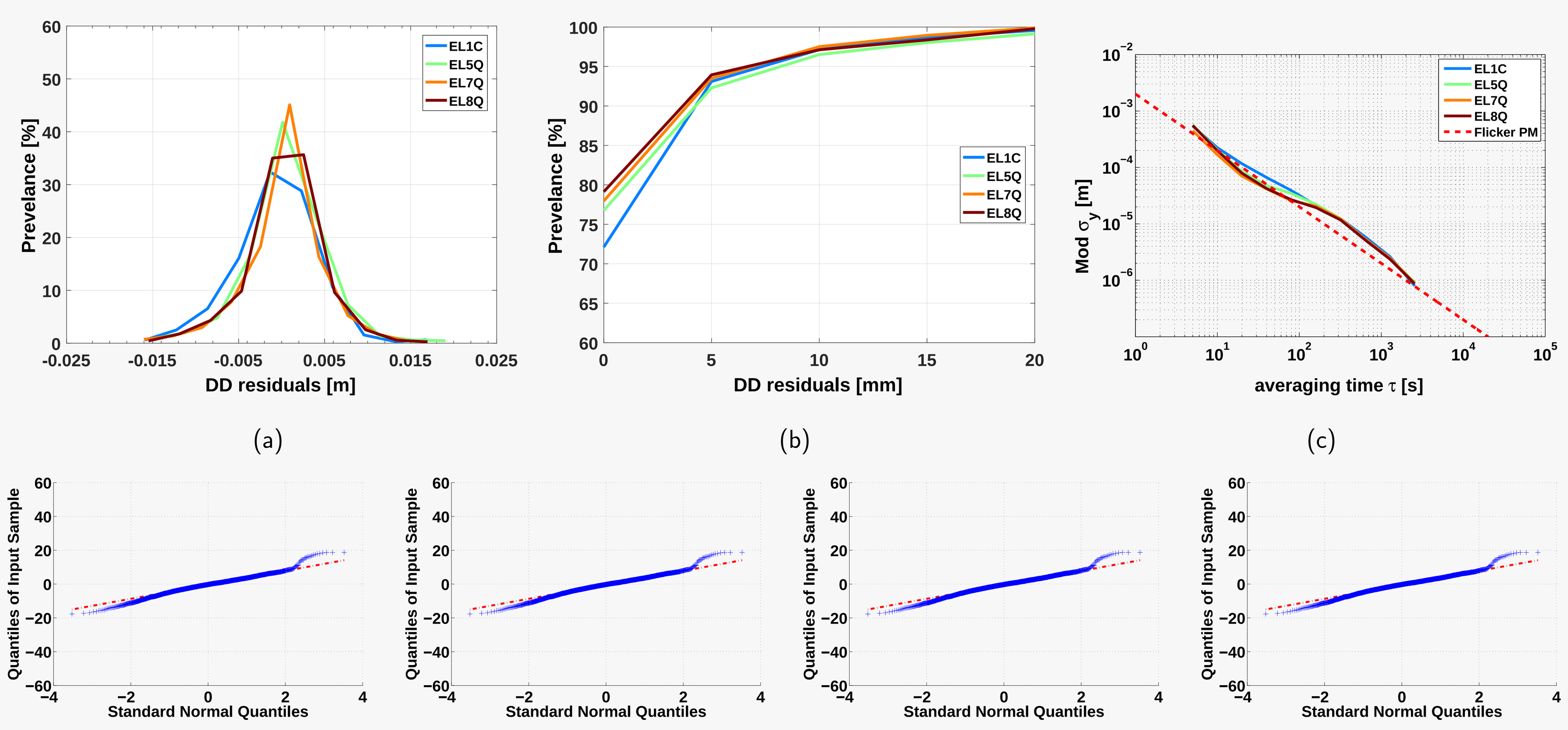
Figure 5: Galileo DD with individual standard deviation, shown here for selected baselines.

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

- Challenging geometry for optimal GNSS satellite tracking at urban GNSS sites.
- Signal E1 (EL1C) indicates higher noise with respect to the other signals, which are close comparable.

HH08 - Residuals of DD show higher magnitudes.

- E1 indicates higher noise than other Galileo signals (ca. 80% below 2 mm).
- Modified Allan standard deviation results to averaging time of 20 sec (linear).
- Graph 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).
- Gradient for signals E5a (EL5Q), E5b (EL7Q) and E5a+b (EL8Q) prove to be -1 and -1,5 (White Phase Moduation (WPM)).



(a) (b) (c)
(d) E1 (EL1C) (e) E5a (EL5Q) (f) E5b (EL7Q) (g) E5a+b (EL8Q)

Figure 6: Statistic Analysis of Galileo DD of baseline DE-01, (a) histogram, (b) cumulative histogram, (c) Allan standard deviation, (d)-(g) and Quantile-Quantile (Q-Q) plots .

Conclusions

- Similar noise and impact for signal E5a+b (EL8Q) and E5a (EL5Q) and E5b (EL7Q).
- Distorted signals as stable as original signals at challenging sites (ref. Fig.4b) even though multipath mitigating equipment was used.

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