GNSS-Monitoring of Surface Displacements in Urban Environments

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Motivation | Why proposing Dynamical Elevation Masks (dynMsk)?

Challenges at urban GNSS sites

- Urban environments challenging for stable and continuous GNSS signal acquisition.
- Intensive station selection possibly not avoid moderate numbers of obstacles at some GNSS sites.
- Classical elevation masks increase risk to erase useful geometry & observations (i.e. not suitable for urban geometry and obstruction situation).

Advantages of dynMsk

- Dynamic and adaptive elevation mask (dynMsk) considers C/N0 power density ratio as quality indicator.
- Noise on double difference observed-minus-computed (DD OMC) and carrier-to-noise (C/N0) pattern reduced.
- Useful tool during data cleaning & outlier removing to improve quality and reliability of estimated parameters.

Requirements for dynMsk

- Consistent receiver-antenna C/N0 reference curve (from absolute antenna calibration) due to individual properties.
- GNSS data (more than 2 hours) and repetition with different satellite geometry to apply *dynMsk*.

GNSS Challenges and Obstructions in Inner Cities

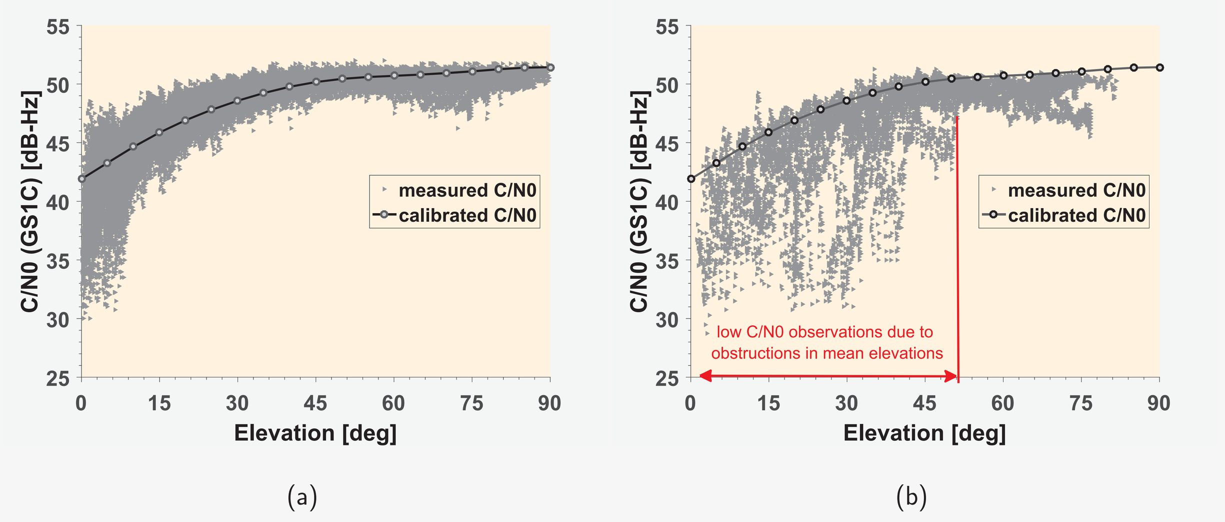

Figure 1: Carrier-to-Noise power density ratio (C/N0) as signal quality indicator, (a) nominal reference curve from laboratory network and 24 hour observation set, (b) observed C/N0 at GRAV12 (Bad Frankenhausen) with the same receiver-antenna combination influenced by urban reflectors.

Carrier-to-Noise power density ratio (C/N0) as signal quality indicator

- Considering site-specific conditions at GNSS sites.
- Signal interruptions depend on elevation **and** azimuth.
- Cleaning input data (separate outliers from unaffected observations) esp. in high elevations.

C/N0 Template Functions

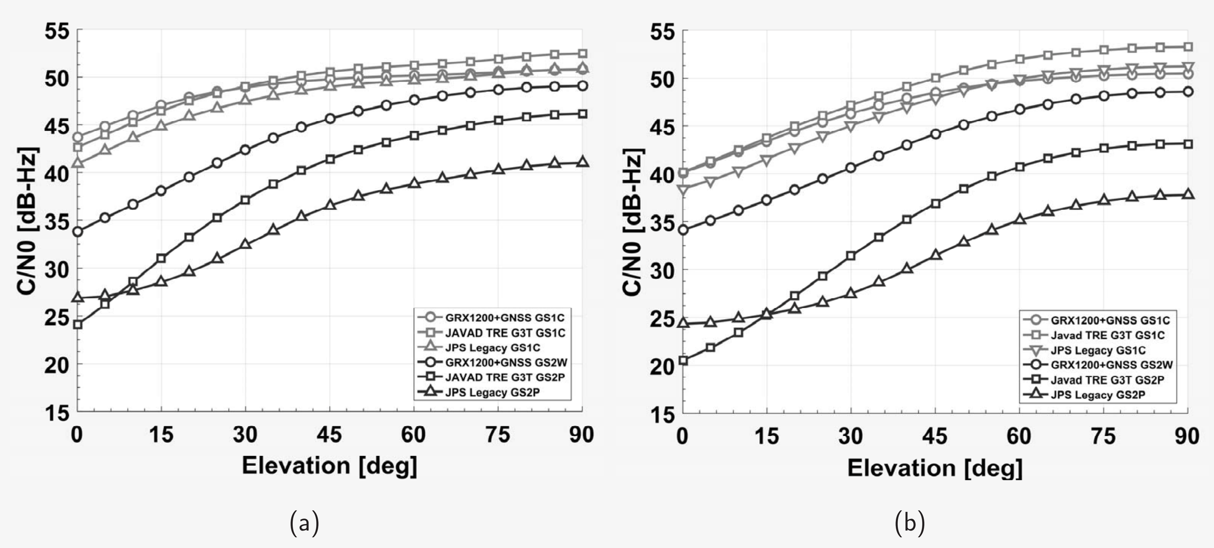

Figure 2: Elevation dependent C/N0 template functions obtained by robot based antenna calibration on a zero baseline approach for several antenna-receiver combinations, (a) Leica AR25.R3 antenna, (b) Trimble Zephyr I Geodetic.

Evaluation using calibrated C/N0 reference curves

- Individual receiver-antenna combinations, consistent C/N0 reference curves required.
- Separation of outliers by threshold of ±3 dB-Hz.
- Writing azimuthal and elevation dependent obstruction mask & RINEX files (Ver. 3.02 / 2.11).

Dynamic and Adaptive Elevation Masks (dynMsk)

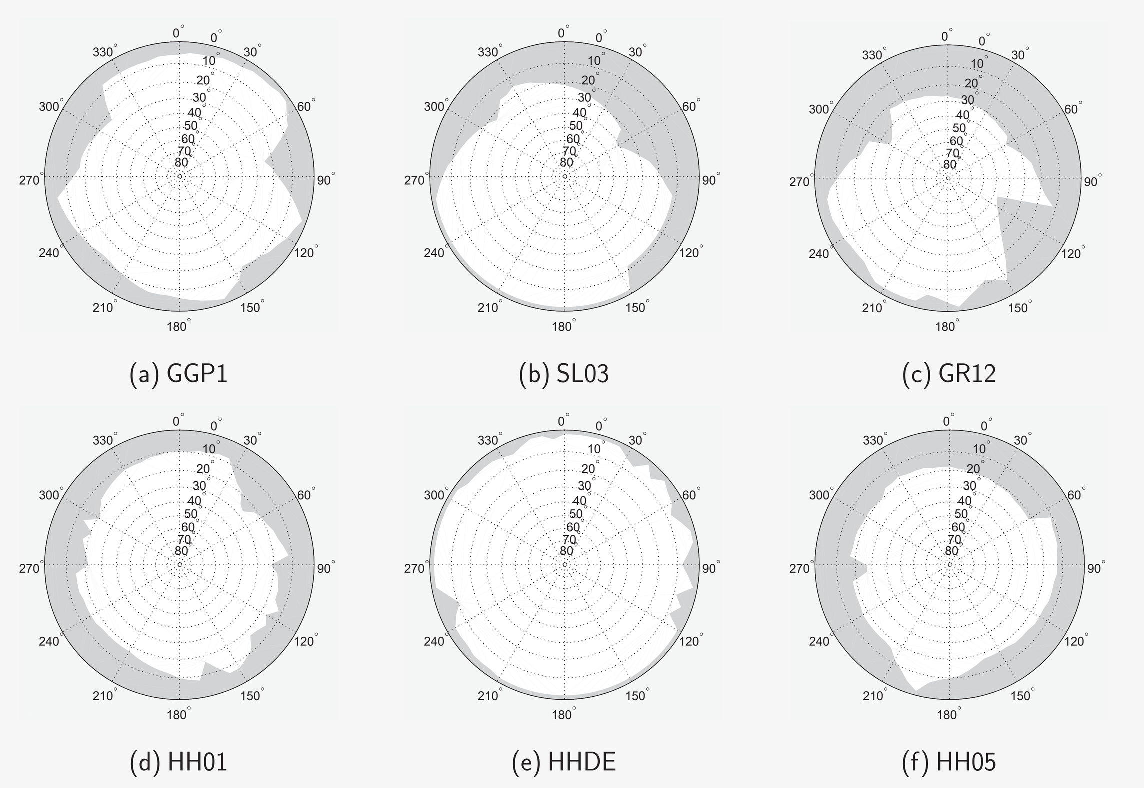

Figure 3: Selected obstruction-skyplots of sites used in urban GNSS monitoring sites (selected) for characterising urban challenges, (a-c) Bad Frankenhausen (Thuringia), (d-f) Hamburg (Groß-Flottbek).

Obtained obstruction masks by dynMsk during 4 hour sessions (repeated)

- Physically meaningful; entire location fully considered.
- Distortions on carrier phase observable correspond to C/N0; identified easily by *dynMsk*.
- Challenging obstructions at GNSS sites GR12, HH01 and HH05 (ref. Fig. 3).

dynMsk | Observation Domain

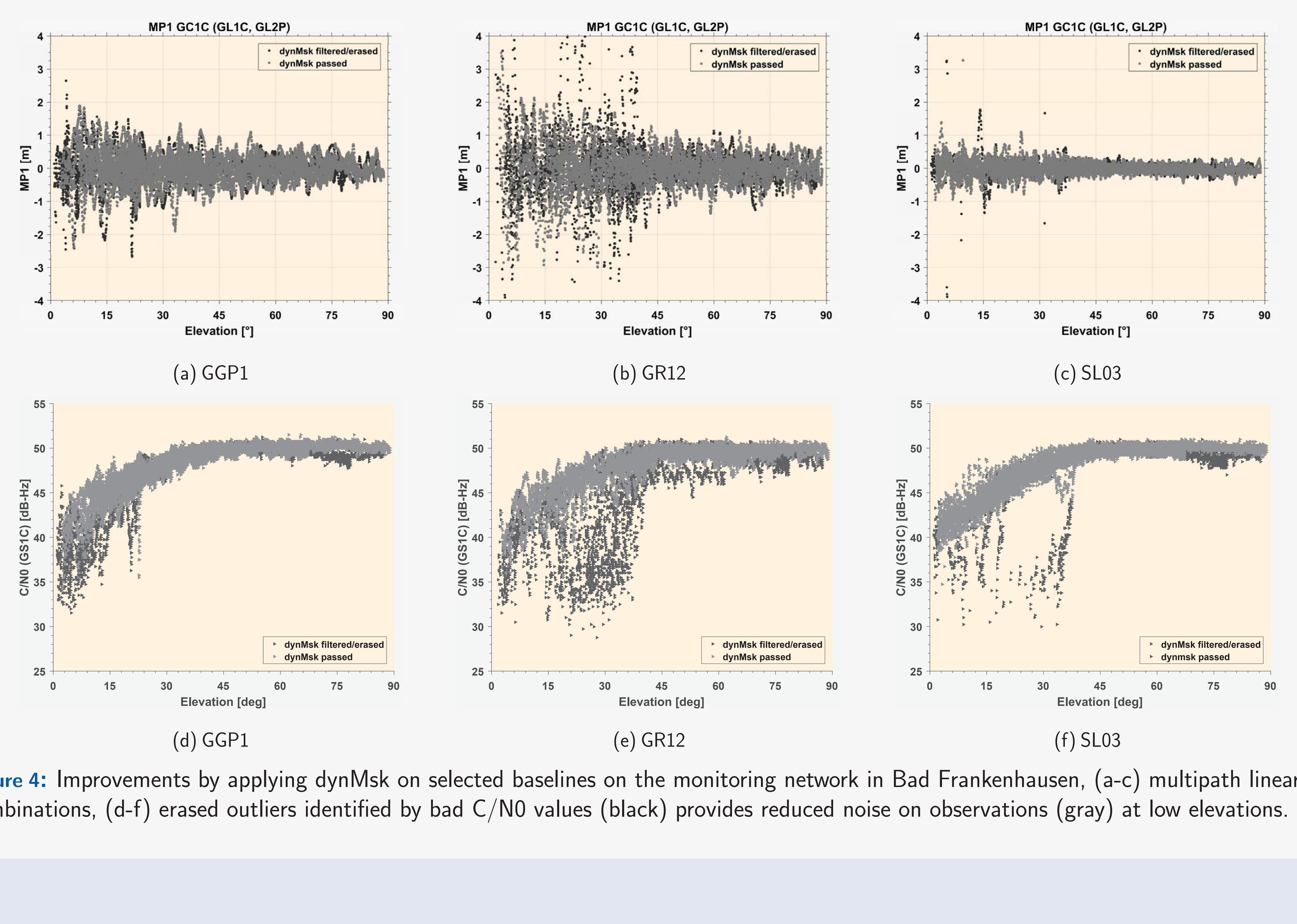

Figure 4: Improvements by applying dynMsk on selected baselines on the monitoring network in Bad Frankenhausen, (a-c) multipath linear combinations, (d-f) erased outliers identified by bad C/N0 values (black) provides reduced noise on observations (gray) at low elevations.

GPS L1 Double Differences | Bad Frankenhausen (Thuringia) - BFH

Findings

- Raw observations successfully cleaned (ref. Fig. 4).
- DD OMC of GPS L1 carrier phase (ref. Fig. 5) show mean deviation of 1.2 cm and outliers of more than 10 cm are removed.
- At low elevations, only outliers are removed, stable DD OMC up to 2° elevation.

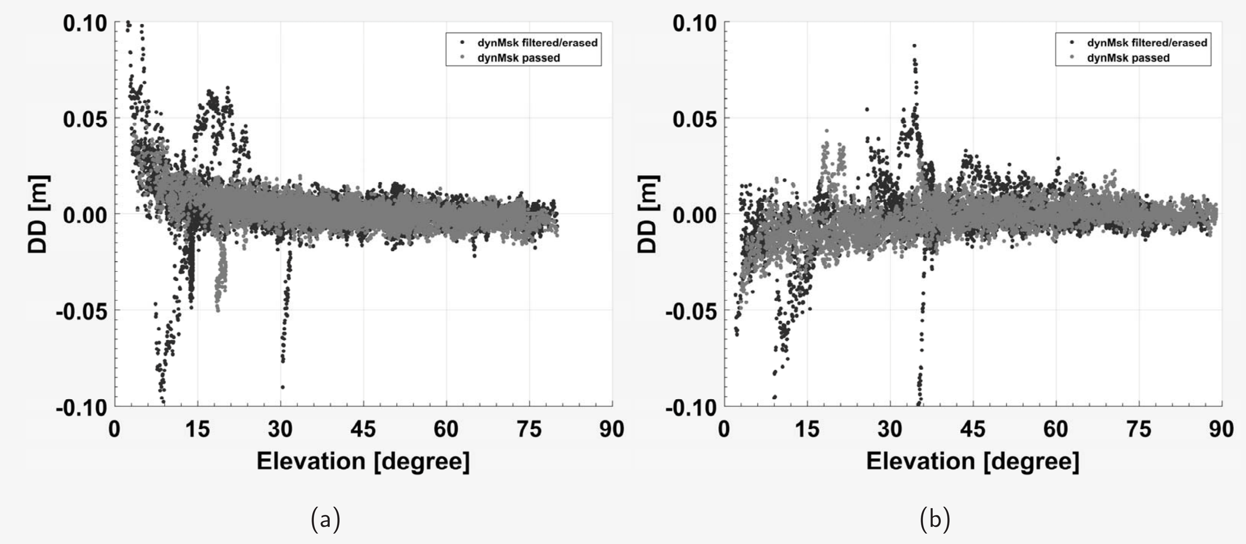

Figure 5: GPS L1 DD OMC for selected baselines in Bad Frankenhausen w/o applying dynMsk at both sites, (a) baseline SL03-GGP1, (b) baseline SL03-GR12. Light grey dots show DD OMC obtained by dynMsk, black dots show observations, erased by the dynMsk.

GPS L1 Network Processing | Bernese

Campaign	Site	dynMsk	Elevation Mask [°]	Elliptical Height [m]	RMS of individual solution north [mm]	east [mm]	up [mm]
BFH -04	GGP1	yes	2	309.6619	1.87	2.46	2.28
BFH -09		yes	2	309.6476	0.89	0.85	3.43
BFH -04		no	25	309.6577	2.15	2.99	5.20
BFH -09		no	25	309.6509	2.32	1.04	2.04
BFH -04	GR11	yes	2	185.8218	0.79	0.96	2.14
BFH -09		yes	2	185.8216	0.57	0.71	2.13
BFH -04		no	25	185.8224	0.72	0.63	1.77
BFH -09		no	25	185.8205	2.60	1.03	2.06
BFH -04	GR12	yes	2	198.4924	0.16	0.95	1.85
BFH -09		yes	2	198.4915	0.76	1.19	1.57
BFH -04		no	25	198.4815	0.34	1.00	1.54
BFH -09		no	25	198.4884	1.26	1.40	5.65

Table 1: Results wrt. GPS L1 solution of selected baselines obtained w/o dynMsk with SL03 as local reference station, processed with Bernese 5.2 for the campaigns in spring (BFH-04) and in autumn (BFH-09).

Processing scheme

- Bernese processing of GPS L1 only network solution, at least 3 sessions per campaign.
- Modified dynMsk RINEX files as input (dynMsk: **yes**).
- Classical elevation mask (dynMsk: **no**).
- CODE products for consistent processing.

Findings

- Selected baselines with challenging sites analysed.
- Improved repeatability for height component in case of *dynMsk*.

GPS L1 Network Processing | Leica LGO 8.4

Processing scheme

- LGO processing of GPS L1 only network solution.
- Modified dynMsk RINEX files as input.
- CODE products for consistent processing and comparisons (ref. Tab. 1).
- BFH: Dataset from Bad Frankenhausen (Thuringia).
- HHX: Dataset from Hamburg Groß-Flottbek.

Campaign	Site	dynMsk	Elevation Mask [°]	Elliptical Height [m]	Quality horizontal+vertical [mm]	horizontal [mm]	vertical [mm]
BFH -04	GGP1	yes	2	309.6647	0.7	0.4	0.6
BFH -09		yes	2	309.6637	1.2	0.6	1.0
BFH -04		no	25	309.6648	1.2	0.6	1.0
BFH -09		no	25	309.6592	1.9	0.9	1.7
BFH -04	GR11	yes	2	185.8169	0.8	0.4	0.7
BFH -09		yes	2	185.8157	1.0	0.5	0.8
BFH -04		no	25	185.8196	1.3	0.7	1.1
BFH -09		no	25	185.8164	1.7	0.8	1.5
BFH -04	GR12	yes	2	198.4831	1.3	0.7	1.1
BFH -09		yes	2	198.4810	2.3	1.3	1.9
BFH -04		no	25	198.4869	2.8	1.5	2.4
BFH -09		no	25	198.4844	3.6	1.7	3.2

Table 2: Results wrt. GPS L1 solution of selected baselines for an urban GNSS monitoring network obtained w/o dynMsk with SL03 as local reference station for the campaigns in spring (BFH-04) and in autumn (BFH-09).

Campaign	Site	dynMsk	Elevation Mask [°]	Elliptical Height [m]	Quality horizontal+vertical [mm]	horizontal [mm]	vertical [mm]
HHX -04	HH01	yes	2	79.3036	1.2	0.6	1.1
HHX -09		yes	2	79.3039	0.8	0.4	0.7
HHX -04		no	25	79.3044	0.8	0.4	0.7
HHX -09		no	25	79.3047	0.9	0.4	0.8
HHX -04	HH05	yes	2	79.9292	2.4	1.1	2.1
HHX -09		yes	2	79.9314	1.1	0.6	0.9
HHX -04		no	25	79.9315	1.7	0.9	1.5
HHX -09		no	25	79.9323	1.5	0.5	0.9

Table 3: Results wrt. GPS L1 solution of selected baselines for an urban GNSS monitoring network obtained w/o dynMsk with HHDE as local reference station for the campaigns in spring (HHX-04) and in autumn (HHX-09).

Findings

- Selected baselines with challenging satellite geometry in urban locations analysed.
- Improved reliability for height component in case of *dynMsk* at HHX and BFH.

Conclusions

- Approach of *dynMsk* allows to model and separate outliers and noisy data physically meaningful by considering variations of data quality by elevation and azimuth.
- Technique reduces noise on the observation domain and improves repeatability of height and horizontal component esp. in cases of challenging satellite geometry at specific GNSS sites.
- As *dynMsk* only relays on the input data and C/N0 template function, it is extremely variable and practical applicable.
- Optimal solutions at urban environments accessible since unexpected and short-time periodic changes of the entire surroundings at GNSS sites often reduce data quality.

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