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Determining GNSS Phase Biases by Common Clock Approaches

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Motivation | Multi-GNSS and Biases - Challenges

GNSS Infrastructure

- New signals and modulations (BPSK, BOC, AltBOC, etc.) and constellations available

GNSS Service and Interoperability

- GNSS data exchange via RINEX 3.0x and RTCM
- IGS station network and analysis centers (MGEX, IGS-RTS (Real Time Service), IGMA (Joint Performance Monitoring))

User Infrastructure

- Different types/brands of high-end GNSS receiver and antenna; broad variety of applications (time, position, navigation, Smart Cities)
- Inhomogeneity of signal tracking (algorithms and approaches)

Necessity for User

- Carrier Phase Biases, improved ambiguity resolution (integer PPP), [Laurichesse et al., 2009]
- Key Parameter for consistent (undifferenced) GNSS processing and / or combination

Table 1: Summary of current satellite systems and signals for GPS, GLONASS, Galileo modified after [Montenbruck et al., 2017]. Specifier IIR, IIR-M, IIF indicate individual GPS generations, IOV indicates In-Orbit Validation, FOC indicates Full Operational Capability. Satellites not declared as operational are indicated by numbers in brackets.

System	Block	Signals	Satellites
GPS	IIR	L1 C/A, L1/L2 P(Y)	12
	IIR-M	L1 C/A, L1/L2 P(Y), L2C, L1/L2 M	7
	IIF	L1 C/A, L1/L2 P(Y), L2C, L1/L2 M, L5	12
GLONASS	M	L1/L2 C/A, P	23
	M+	L1/L2 C/A & P, L3	1
	K	L1/L2 C/A & P, L3	1+(1)
Galileo	IOV	E1 E6, E5a/b/ab	3+(1)
	FOC	E1 E6, E5a/b/ab	6+(4)
BeiDou-3	MEO	B1-2, B1, B2, B3ab	

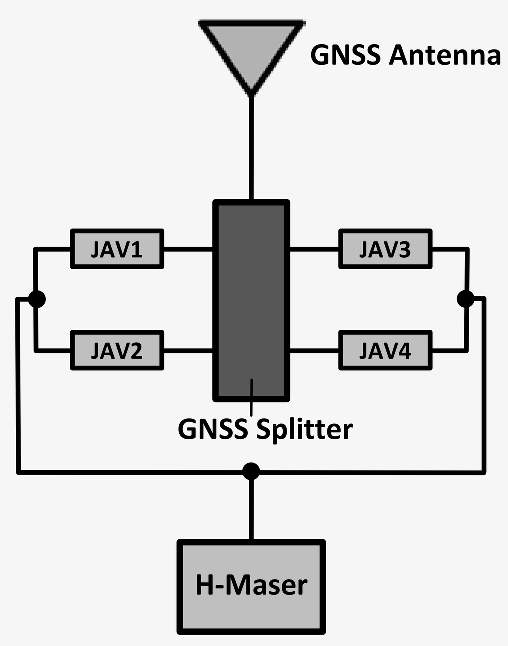
Methodology | Determine Phase Biases alternatively

Key Idea

- Calibration of receiver carrier phase biases on zero baseline (ZB, cf. Fig. 1(a)) with common clock (CC) with an ultra stable & precise external Frequency Standard (cf. Fig. 1(b)).
- Observable: receiver-to-receiver single differences (RRSD) between stations A, B and a satellite j

$$\Delta\Phi^j_{A,B} = \underbrace{c(\delta t_A - \delta t_B)}_{\text{constant per switch-on \& freq independent}} + \underbrace{\lambda(N^j_A - N^j_B)}_{\text{constant per satellite arc}} + \underbrace{d^j_{\Phi,A} - d^j_{\Phi,B}}_{\text{constant \& frequency dependent}}.$$

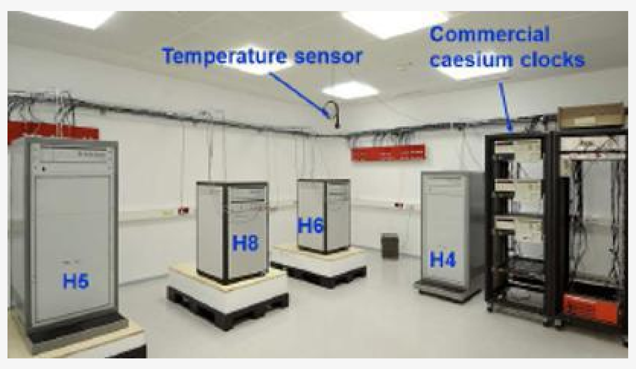
- Obtain initial Carrier Phase Biases between frequencies and signals (fractional nature).



(a) Experimental setup

Calibration Procedure

- RINEX 3.0x for consistent exchange of GNSS observables irrespective of individual manufacture, [Gurtner und Estey, 2015]
- Reduce most of GNSS errors by ZB & CC approach (ultra stable H-Maser, Fig. 1(b))
- Remove potential drifts and quadratic terms (i.e. temperature effects etc.) and process:
  1. Determine ambiguities by rounding w.r.t. corresponding wavelength $\lambda\Delta N^j_{AB}$,
  2. Elimination of common differential receiver clock parameter $c\Delta\delta t_{AB}$
  3. Estimation and analysis of receiver carrier phase biases $\Delta d^j_{\Phi_{AB}}$



(b) Bundle of H-Masers @ PTB / Kopfermannbau

Figure 1: Experimental setup for carrier phase bias calibration at the PTB facility, (a) zero baseline & common clock receiver setup, (b) facility of active H-Maser for supporting UTC(PTB).

Receiver-to-Receiver Single Differences - Channels and Modulations

Key parameters

- Four GNSS receiver of same type (`Javad TRE_G3T`, same Firmware), configuration cf. Fig. 1(a)
- Data stored and analysed for three consecutive days, 1 sec data sampling
- Data processing with in-house implemented software (IfE-GNSS-Toolbox V6.1, research & teaching)

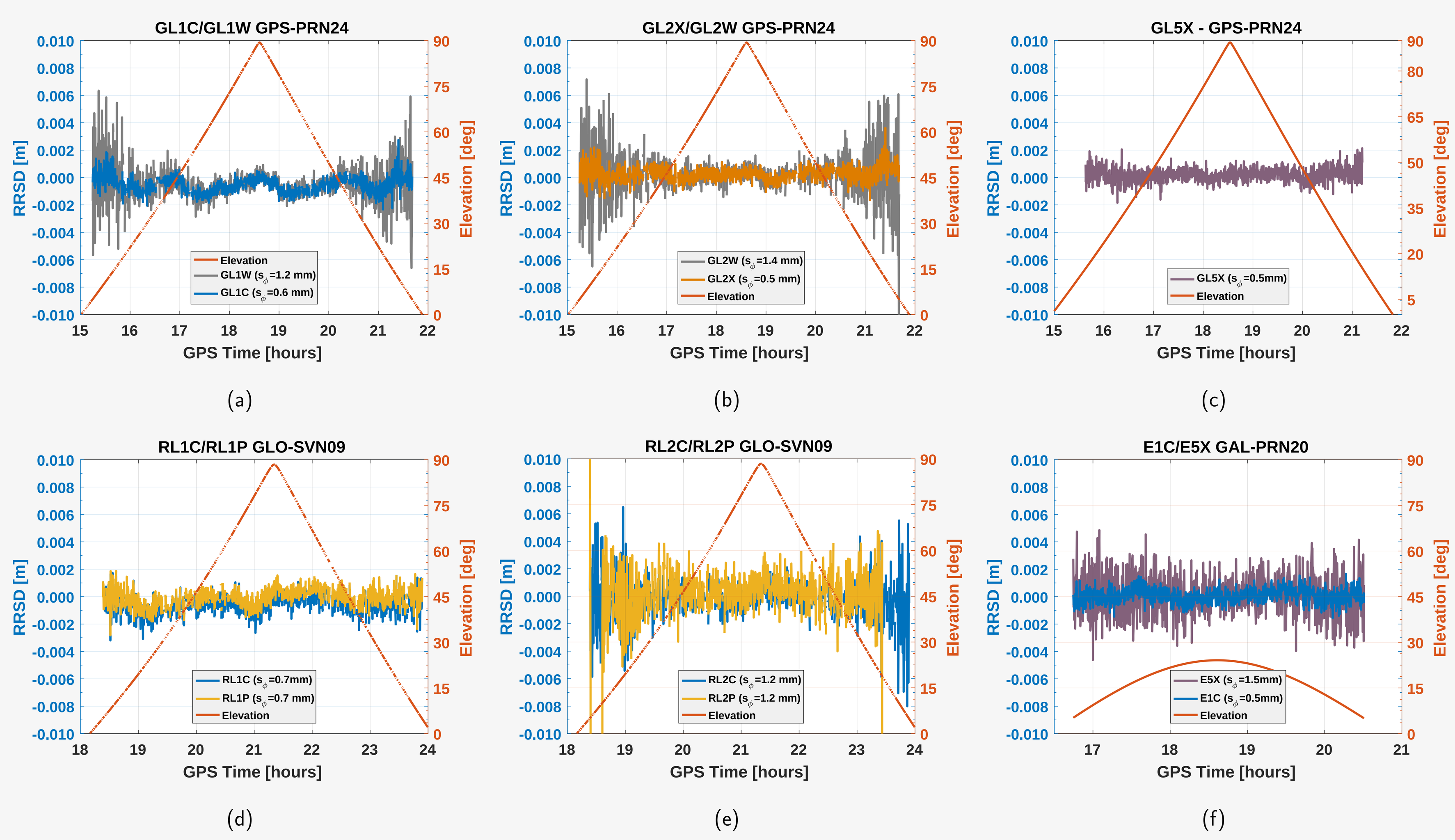


Figure 2: Individual RRSD for various GNSS, signals and modulations shown exemplary for individual satellites, (a-c) GPS, (d-e) GLONASS and (e) Galileo. Individual standard deviations (s_0) of RRSD indicate precise observations and a stable repeatability. Individual offsets removed for comparison reasons. Variations of the single differences origin from both, environmental conditions inside the laboratory and corresponding (possible) delays in the cables from the splitter. RRSD refer to the baseline JAV3-JAV1.

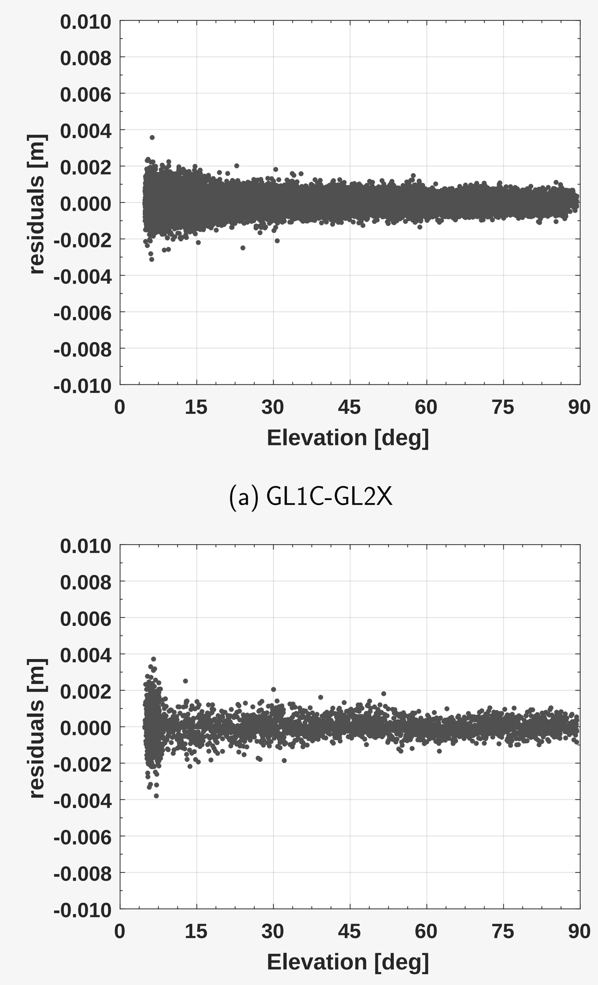
Findings in the observation domain

- Elevation dependent noise of RRSD for Z-tracking (RINEX indicator: **W**) below 16° elevation on GPS L1W and L2W as well as for GLONASS L2C/L2P
- Signal specific variations of less than 1.2 mm origin from the laboratory environment (receiver housing, calbes)
- Noise of RRSD observables between 1.2 mm (GL1W/GL2W, RL2C/RL2P, E5X) and 0.5 mm (GL1C, GL2X, GL5X, RL1C/RL1P)

Receiver Carrier Phase Biases

Rx 1	Rx 2	Baseline	PHASE_BIAS	Bias Values DOY056 [m]	DOY057 [m]	DOY058 [m]
JAV2	JAV1	1	GL2X-GL2W	0.0011	0.0010	0.0010
			GL1C-GL1W	0.0000	0.0000	0.0000
			GL1C-GL2X	0.0002	0.0007	0.0006
			GL1C-GL2W	-0.0002	-0.0004	-0.0001
			GL1C-GL5X	0.0073	0.0071	0.0068
JAV3	JAV1	2	GL2X-GL2W	0.0011	0.0010	0.0010
			GL1C-GL1W	0.0000	0.0000	0.0000
			GL1C-GL2X	0.0075	0.0075	0.0076
			GL1C-GL2W	0.0061	0.0062	0.0065
			GL1C-GL5X	-0.0061	-0.0061	-0.0062
JAV4	JAV1	3	GL2X-GL2W	0.0025	0.0028	0.0026
			GL1C-GL1W	0.0003	0.0003	0.0003
			GL1C-GL2X	0.0081	0.0085	0.0082
			GL1C-GL2W	0.0066	0.0069	0.0072
			GL1C-GL5X	-0.0007	-0.0003	-0.0005

Table 2: Estimated receiver initial phase biases for several signals and frequencies with daily repetition to indicate the stability of the presented calibration approach.

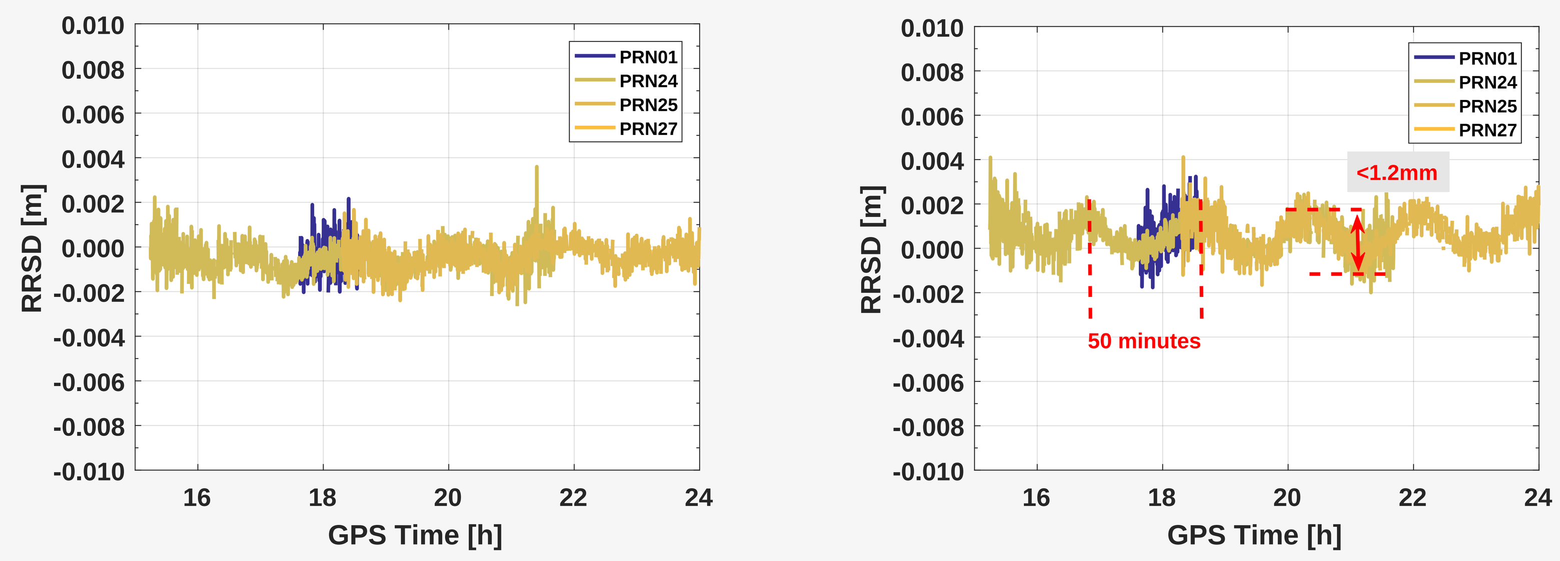


(a) GL1C-GL2X

(b) GL1C-GL5X

Figure 3: Residuals of initial phase bias estimation for several signal combinations.

Challenges and Side-Effects



(a) JAV3-JAV1 (GL5X)

(b) JAV4-JAV1 (GL5X)

Figure 4: Variations on the carrier phases exemplarily shown for two receiver combinations and one signal (GL5X). Variations origin from the receivers entire environment; observation data has to be corrected for such and similar effects. Additionally, the calibration setups has to be prepared and processed with *special* care (i.e. cable length, phase stable cables etc.).

- High sensitive laboratory setup w.r.t. environmental conditions, i.e. temperature effects are directly mapped into the observation domain
- Periodic variation of 50 minutes with amplitudes of <1.2 mm origin from the air condition controller
- Consequently, effects have to be considered during data processing

Receiver Differential Code Biases

GNSS	DCB	Δ [m]	daily scatter [m]
GPS	C2X-C1C	0.22	0.05
	C5X-C1C	0.24	0.05
GLONASS	C2C-C1C	0.40	0.10
	C1P-C1C	0.10	0.08
	C2P-C1C	0.40	0.10
Galileo	C5X-C1C	0.25	0.05

Table 3: Estimated Differential Code Biases for several systems and signals. Results exemplary shown for some combinations.

Findings & Statements

- Differential code Biases estimable within the approach (reference C1C)
- Independent of global network infrastructure
- Calibration with timing receiver and known delays for absolute correction
- values as reference for DCB should based on physical considerations
- monitoring and analysing DCB stability of certain receiver/receiver groups (relative/absolute)

Conclusions and Further Steps

Conclusions

- Independent approach for calibration of receiver carrier phase biases
- Excellent approach for calibration of code and carrier phase biases independently of global network infrastructure
- Results are stable, accurate and precise w.r.t. individual measurement noise
- Asymmetry of calibration setup causes drifts of some millimetres (consider phase-stable cables, splitters and similar cable lengths)

Steps for further Investigations @ IfE

- Strong relation to entire receiver environment (potential to analyse temperature effects at GNSS receiver)
- Complex system calibration (antenna - cable - receiver)
- Integrity check for individual GNSS satellites
- Study of carrier phase bias characteristics of phase bias an corresponding uncertainties
- Consistent study of different receiver branches, signals, tracking algorithms and complete Loss-of-Lock scenarios

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