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Quantifying the pilot-data bias on all current GNSS signals and satellites

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Objective

Modern GNSS signals are made of two components, pilot and data.

→ multiple flavors of observable. Eg for GPSL5 in RINEX:

GPS	L5/1176.45	I	C5I	L5I	D5I	S5I
		Q	C5Q	L5Q	D5Q	S5Q
		I+Q	C5X	L5X	D5X	S5X

←Data
←Pilot
←Mixed

Pilot and Data signals not perfectly aligned in satellite

→ Satellite-dependent biases between pilot, data and mixed observables.

What are the biases between the Data, Pilot and Mixed observables in currently available signals?

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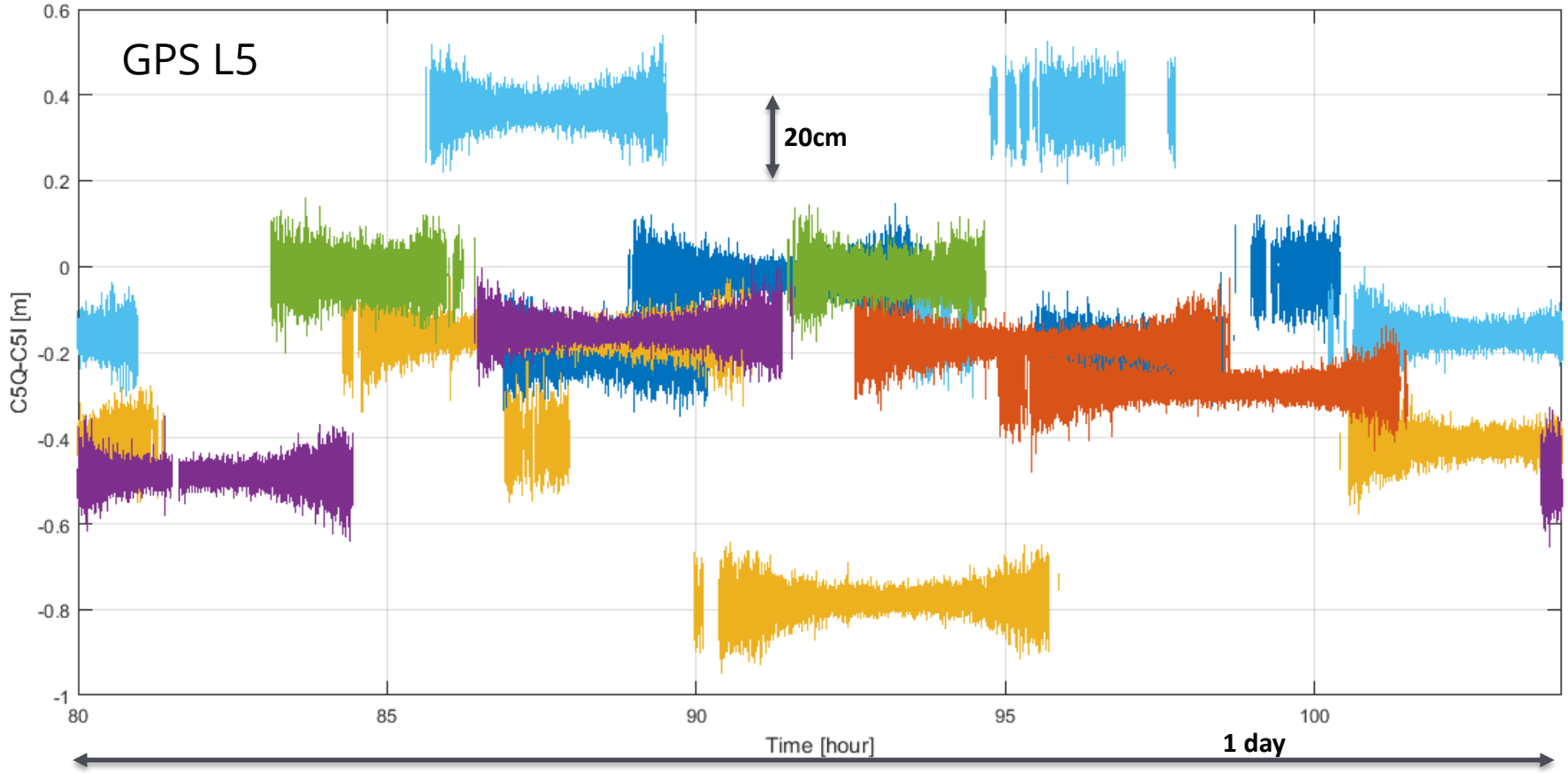
Methodology

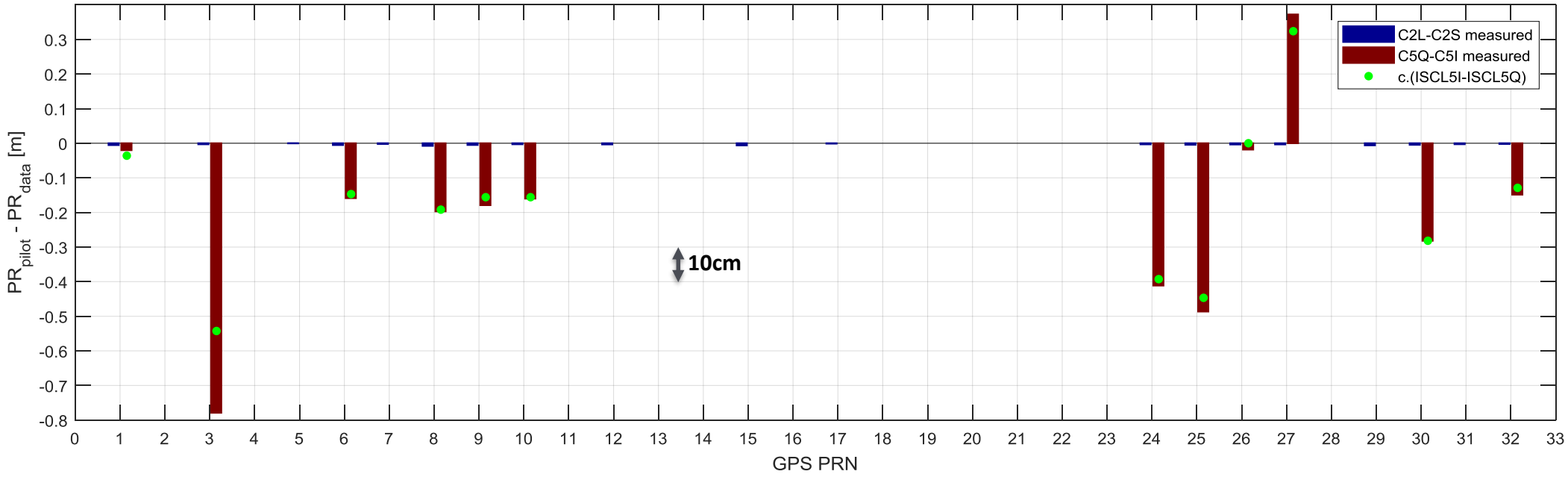
Pilot and Data tracked independently in parallel on the same receiver (PolaRx5 with modified fw)

All receiver effects cancel. Direct access to the satellite pilot-data biases on code and carrier

Done for all GPS, BeiDou, Galileo and QZSS signals



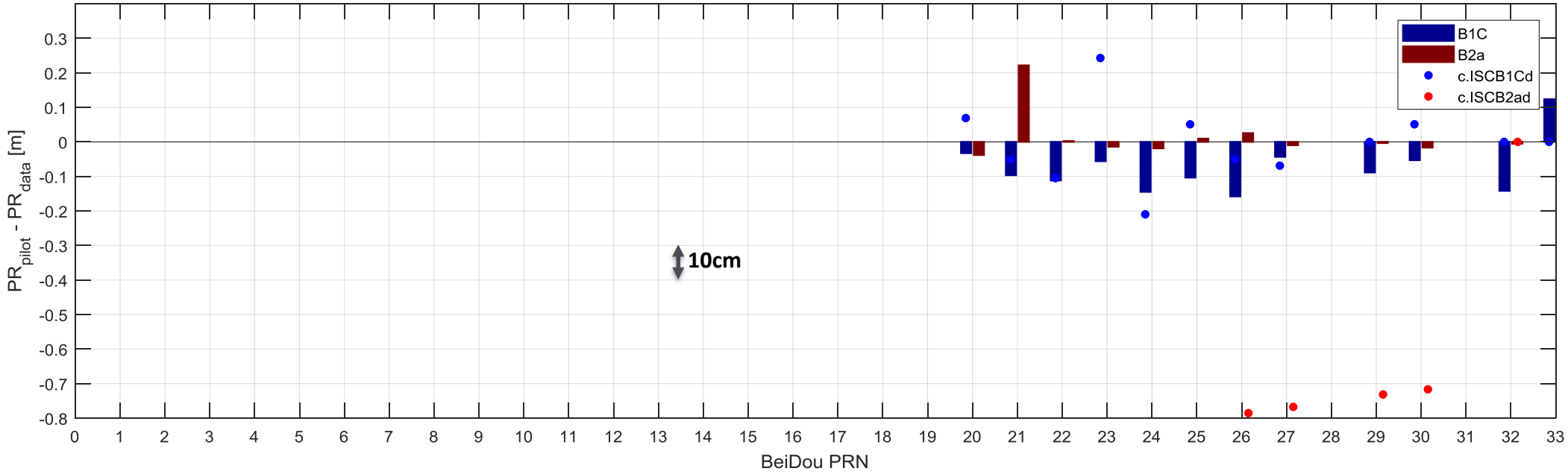
GPS Code Pilot-Data Biases



Pilot&Data components on L2C and L5

- L2C: no PD biases (expected as time-multiplexed on same carrier)
- L5: significant biases, good match with ISC from the CNAV message (except G03)

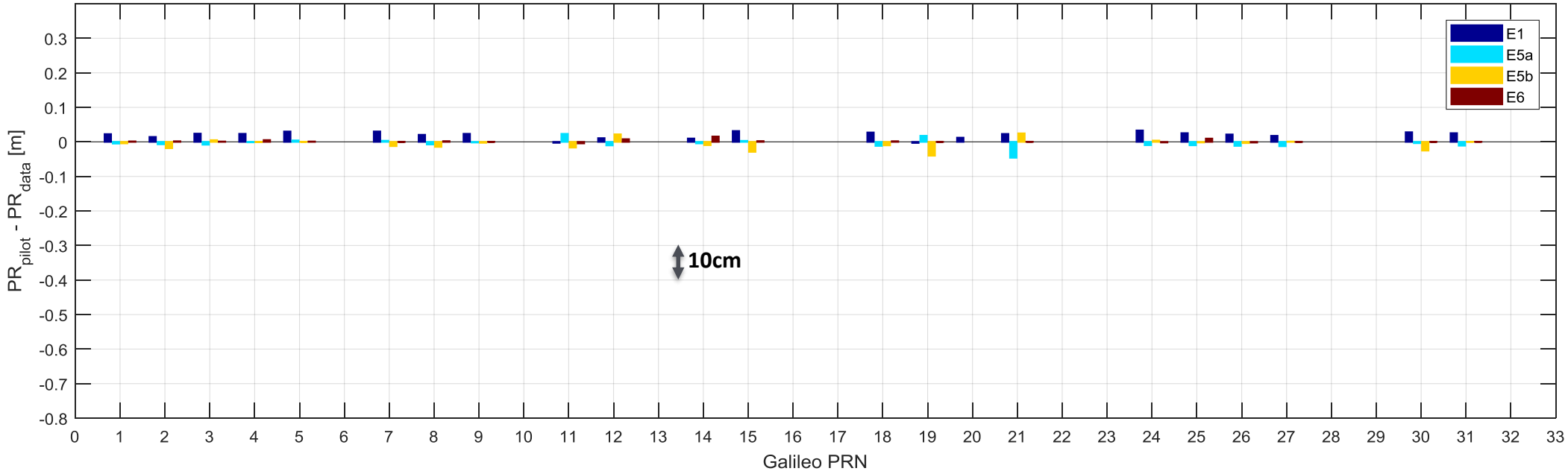
BeiDou Code Pilot-Data Biases



Pilot&Data components on B2a and B1C (BDS-3 only):

- ISCs preliminary (all BDS-3 sats flagged unhealthy at the time of the data collection)

Galileo Code Pilot-Data Biases



Pilot&Data components on E1, E5a, E5b and E6

- All biases < 3cm
- Most significant bias for E1 (expected as E1C and E1B use slightly different modulations)
- No ISC in nav message (not needed considering the small size of biases)

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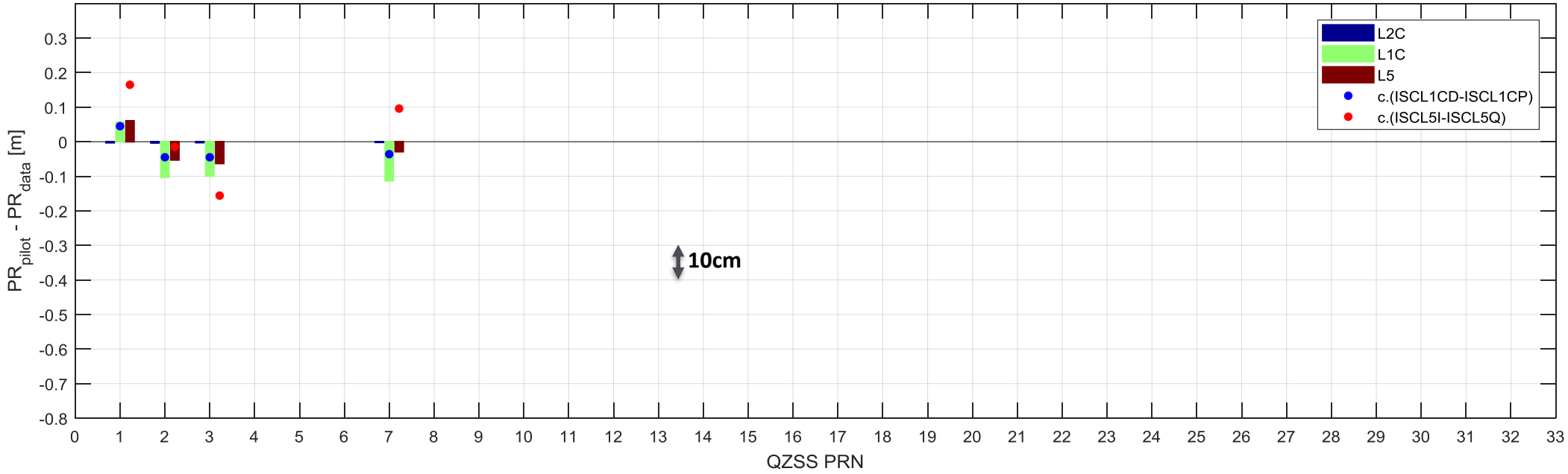
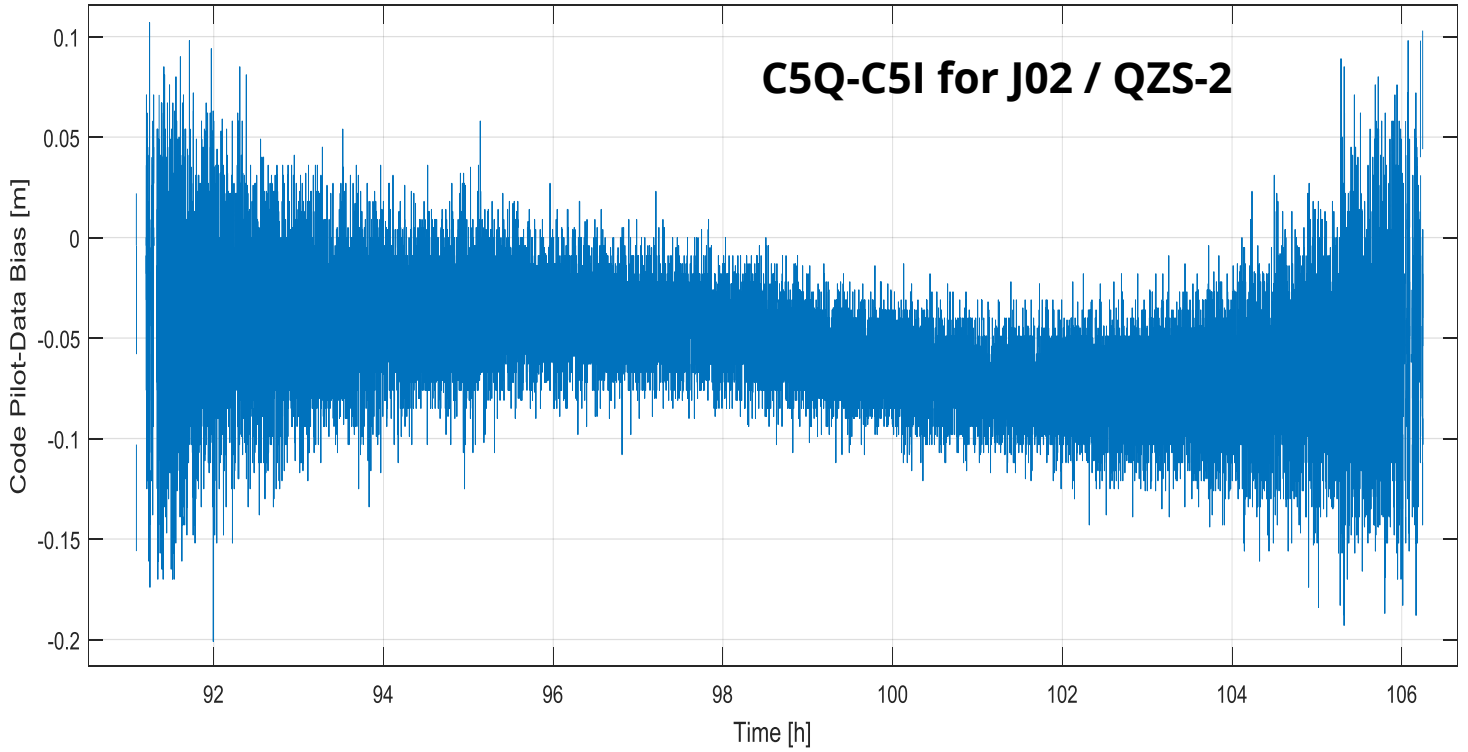
QZSS Code Pilot-Data Biases



Pilot&Data components on L2C, L1C and L5

- Some mismatch with ISC from nav message (NB: transmitted ISC are not constant on QZSS)

QZSS L5 Code Pilot-Data Bias Not Constant



Unique in all constellations:

QZSS L5 PD code biases (C5Q-C5I) are not constant for J02 (QZS-2) and J03 (QZS-4).

Linked to multipath from L5S from other antenna?

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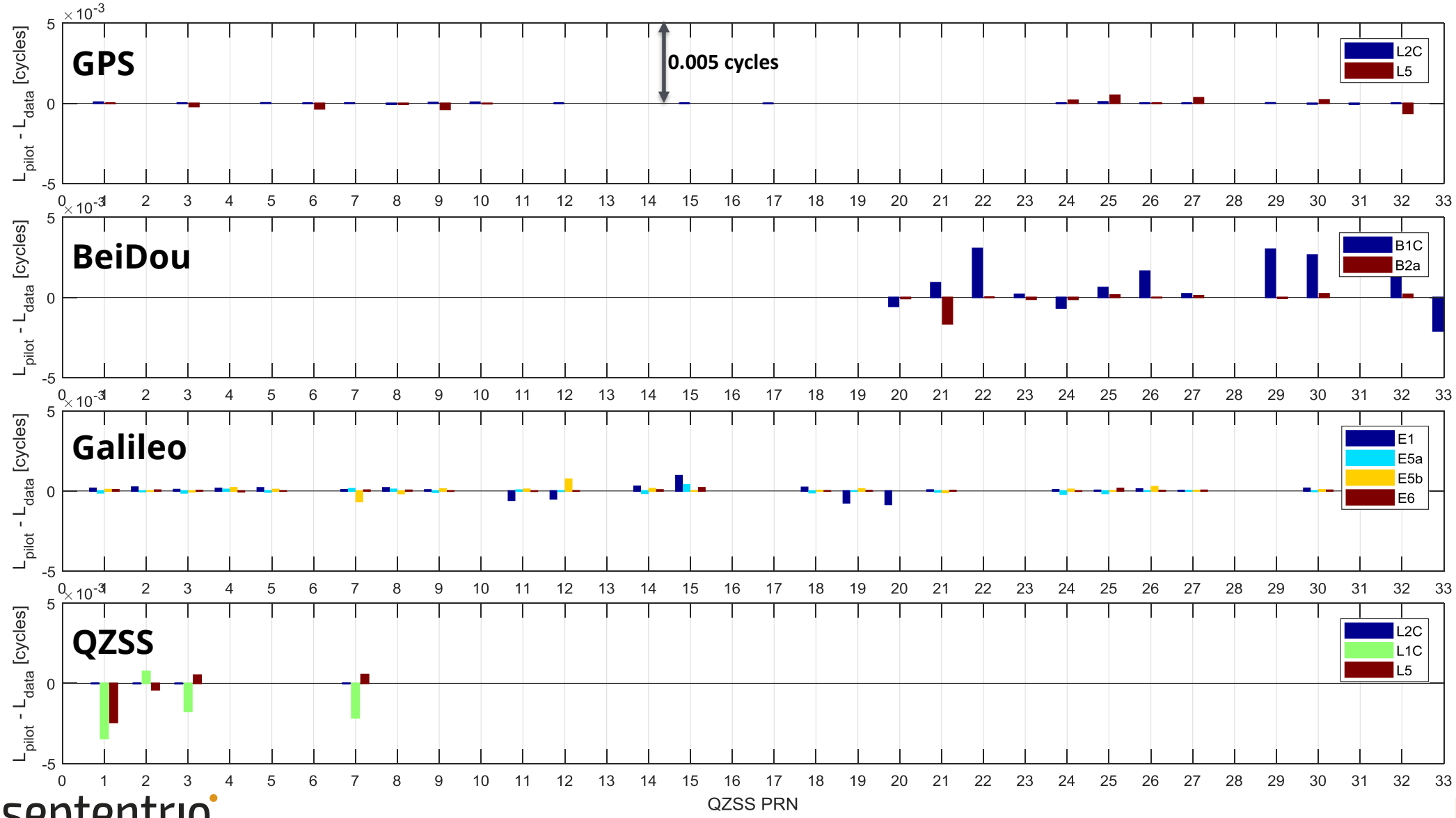
→ Satellite DCBs not constant on L5 for some QZSS satellites

Carrier Phase Pilot-Data Biases



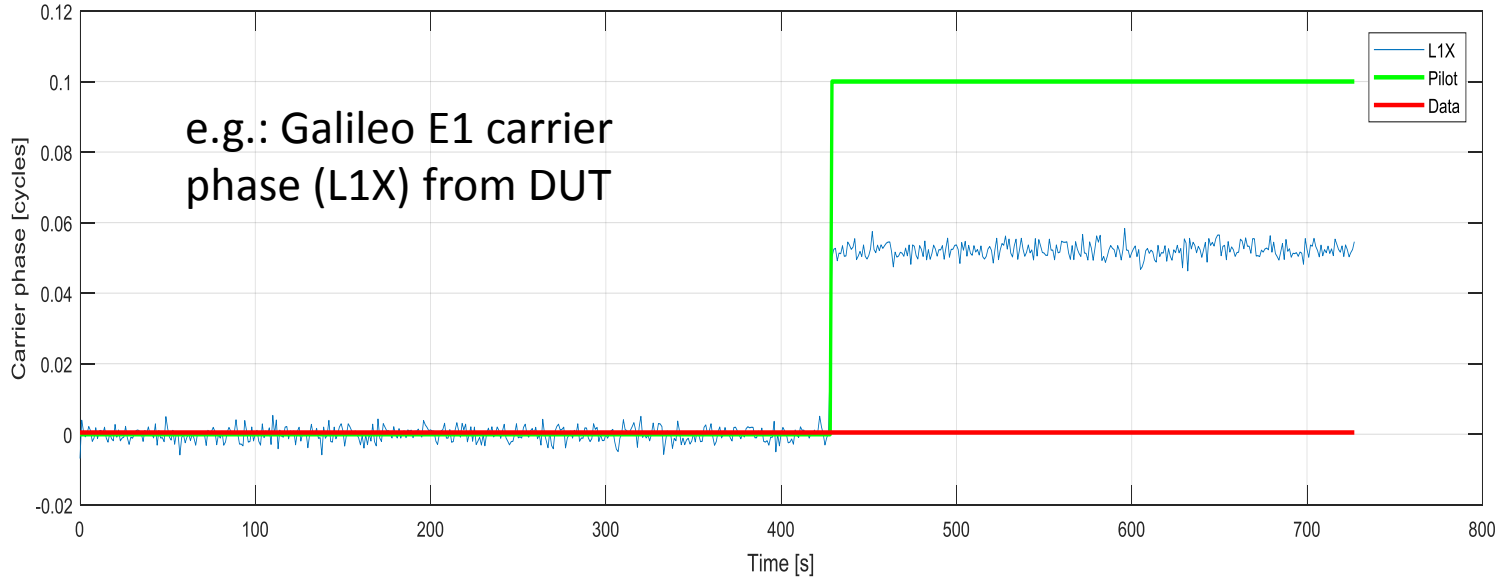
Carrier Pilot-Data biases <0.003 cycles in any constellations

Demystifying the X Observable

X observable usually undocumented by vendor: what to expect?

Reverse engineering procedure:

- Use a Spirent simulator to simulate known pilot-data bias pattern and see how X observable reacts



In this case, X observable is the average of Pilot and Data observable. Bias between pilot and X observables is half of the Pilot/Data bias.

Conclusions

Code pilot-data biases:

- typically dm level
- largest for GPS L5 (but good match with ISC in CNAV), lowest for Galileo (cm-level)
- QZSS peculiarity: variable bias on L5

Phase pilot-data biases

- <0.003 cycles on all constellations
- Probably negligible in most cases

X observables

- Can be “reverse-engineered” using a simulator

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GPS Code Pilot-Data Bias Values

PRN	C2L-C2S [m]	C5Q-C5I [m]
G01	-0.007	-0.020
G02	NaN	NaN
G03	-0.004	-0.779
G04	NaN	NaN
G05	-0.001	NaN
G06	-0.005	-0.159
G07	-0.002	NaN
G08	-0.007	-0.197
G09	-0.005	-0.179
G10	-0.004	-0.160
G11	NaN	NaN
G12	-0.003	NaN
G13	NaN	NaN
G14	NaN	NaN
G15	-0.007	NaN
G16	NaN	NaN
G17	-0.001	NaN
G18	NaN	NaN
G19	NaN	NaN
G20	NaN	NaN
G21	NaN	NaN
G22	NaN	NaN
G23	NaN	NaN
G24	-0.003	-0.411
G25	-0.005	-0.486
G26	-0.003	-0.019
G27	-0.004	0.372
G28	NaN	NaN
G29	-0.007	NaN
G30	-0.005	-0.282
G31	-0.002	NaN
G32	-0.002	-0.149

BeiDou Code Pilot-Data Bias Values

PRN	C1P-C1D [m]	C5P-C5D [m]
C01	NaN	NaN
C02	NaN	NaN
C03	NaN	NaN
C04	NaN	NaN
C05	NaN	NaN
C06	NaN	NaN
C07	NaN	NaN
C08	NaN	NaN
C09	NaN	NaN
C10	NaN	NaN
C11	NaN	NaN
C12	NaN	NaN
C13	NaN	NaN
C14	NaN	NaN
C15	NaN	NaN
C16	NaN	NaN
C17	NaN	NaN
C18	NaN	NaN
C19	NaN	NaN
C20	-0.034	-0.039
C21	-0.097	0.221
C22	-0.112	0.002
C23	-0.056	-0.014
C24	-0.144	-0.019
C25	-0.104	0.008
C26	-0.158	0.025
C27	-0.043	-0.010
C28	NaN	NaN
C29	-0.088	-0.004
C30	-0.054	-0.017
C31	NaN	NaN
C32	-0.141	-0.005
C33	0.123	-0.009

Galileo Code Pilot-Data Bias Values

PRN	C1C-C1B [m]	C5Q-C5I [m]	C7Q-C7I [m]	C6C-C6B [m]
E01	0.023	-0.005	-0.005	0.002
E02	0.015	-0.007	-0.018	0.002
E03	0.024	-0.008	0.005	0.001
E04	0.023	-0.001	-0.001	0.005
E05	0.031	0.004	0.000	0.002
E06	NaN	NaN	NaN	NaN
E07	0.030	0.003	-0.012	-0.001
E08	0.020	-0.008	-0.014	0.002
E09	0.023	-0.002	-0.003	0.000
E10	NaN	NaN	NaN	NaN
E11	-0.002	0.023	-0.017	-0.005
E12	0.011	-0.010	0.021	0.008
E13	NaN	NaN	NaN	NaN
E14	0.010	-0.004	-0.010	0.014
E15	0.029	0.003	-0.028	0.005
E16	NaN	NaN	NaN	NaN
E17	NaN	NaN	NaN	NaN
E18	0.027	-0.012	-0.010	0.002
E19	-0.003	0.018	-0.040	-0.000
E20	0.012	NaN	NaN	NaN
E21	0.023	-0.046	0.025	0.000
E22	NaN	NaN	NaN	NaN
E23	NaN	NaN	NaN	NaN
E24	0.034	-0.009	0.004	-0.001
E25	0.025	-0.010	-0.002	0.010
E26	0.021	-0.012	-0.004	-0.002
E27	0.017	-0.013	0.001	-0.001
E28	NaN	NaN	NaN	NaN
E29	NaN	NaN	NaN	NaN
E30	0.028	-0.004	-0.026	-0.000
E31	0.025	-0.011	0.000	0.000
E32	NaN	NaN	NaN	NaN
E33	NaN	NaN	NaN	NaN

QZSS Code Pilot-Data Bias Values

PRN	C2L-C2S [m]	C1L-C1S [m]	C5Q-C5I [m]
J01	-0.003	0.057	0.060
J02	-0.004	-0.102	-0.053
J03	-0.003	-0.100	-0.063
J04	NaN	NaN	NaN
J05	NaN	NaN	NaN
J06	NaN	NaN	NaN
J07	-0.001	-0.112	-0.029

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