Effects of Frequency-dependent PCOs on DCB Estimates

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Knowledge for Tomorrow

DLR

Agenda

- Effects of PCOs on estimated DCBs

- Frequency-dependent PCOs in IGS ATX14

- Examples for estimated DCBs with/without modelled PCOs

- BeiDou-2 group-delay variations and other signal biases

- Summary & recommendations

Effects of PCOs on Estimated DCBs

DCBs   Code Observations   Ionospheric Delay

$$d_{r,ij} + d_{ij}^s = (p_j - p_i) - (\mu_j - \mu_i)I_1$$

Phase-Center Offsets $\left\{ - \boldsymbol{e}^T \left(\Delta \boldsymbol{r}_{r,j} - \Delta \boldsymbol{r}_{r,i} \right) + \boldsymbol{e}^T \left(\Delta \boldsymbol{r}_j^s - \Delta \boldsymbol{r}_i^s \right) \right.$

Group-Delay Variations $\left\{ - \left(\xi_{r,j} - \xi_{r,i} \right) - \left(\xi_j^s - \xi_i^s \right) \right.$

- Satellite and station PCOs (and GDVs) map into estimated DCBs

- In the past same satellite PCO value for all frequencies in IGS ANTEX

- Different situation for new GPS satellite types and latest GNSSs

- Must be modeled consistently by analysis centers and users

Effect of PCOs on Estimated DCBs
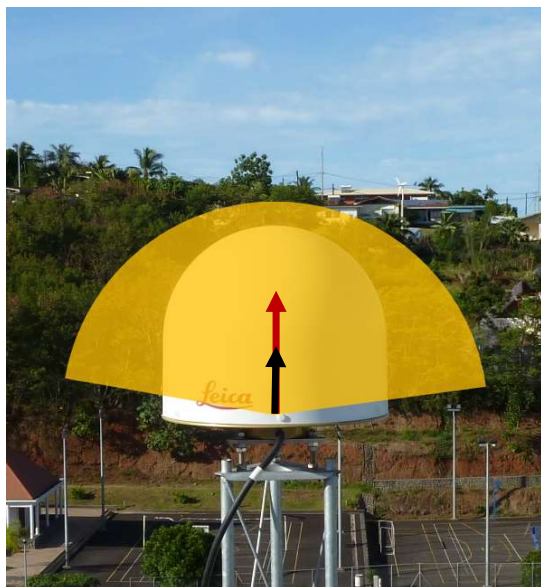
- Maximum off-zenith angle: 90°

- Z-offset mapping on LOS: 0% - 100%

- Z-offset differences up to several centimeters

→ Station antenna PCOs can be ignored!

- Maximum off-nadir angle: 12°…15° (@MEO)

- Z-offset mapping on LOS: 96% - 100%

- Z-offset differences up to several decimeters

→ Satellite antenna PCOs must be modeled!

Frequency-Dependent PCOs in IGS ATX14

- GPS IIIA and BeiDou-2/-3 → block-specific PCOs

- Galileo and QZSS → satellite-specific PCOs

- BeiDou-3 → same PCOs for "adjacent" frequencies (B1/B1-2 and B2a/B2b)

GNSS	PCO z-Offset [m]		
BeiDou-2	**B1**	**B3**	**B2**
IGSO/GEO	3.500	2.770	3.500
MEO	2.120	1.940	2.120
BeiDou-3	**B1 & B1-2**	**B3**	**B2a & B2b**
MEO-SECM	1.100	1.090	1.090
MEO-CAST	1.460	1.180	1.070
IGSO	1.990	1.630	1.560
GEO-CAST	2.090	1.740	1.640

GNSS	PCO z-Offset [m]			
GPS	**L1**	**L2**	**L5**	**--**
IIIA	1.232	0.741	0.779	--
Galileo	**E1**	**E6**	**E5b**	**E5a**
IOV (E102)	0.845	0.740	0.809	0.781
FOC (E208)	0.724	0.676	0.650	0.606
QZSS	**J1**	**J6**	**J2**	**J5**
QZO (J002)	2.394	3.314	3.209	3.154
QZO (J005)	2.917	3.037	2.797	2.597

Frequency-Dependent PCOs in IGS ATX14

- GPS IIIA and BeiDou-2/-3 → block-specific PCOs

- Galileo and QZSS → satellite-specific PCOs

- PCO Z-offset differences smallest for Galileo, largest for QZSS

GNSS	Delta PCO Z-Offset [cm]	
BeiDou-2	B1-B3	B1-B2
IGSO/GEO	73.0	--
MEO	18.0	--
BeiDou-3	B1-B3	B1-B2a/b
MEO-SECM	1.0	1.0
MEO-CAST	28.0	39.0
IGSO	36.0	43.0
GEO-CAST	35.0	45.0

| GNSS	Delta PCO Z-Offset [cm]		
GPS	L1-L2	L1-L5	
IIIA	49.2	45.4	
Galileo	E1-E6	E1-E5b	E1-E5a
IOV & FOC	+1.5...+10.4	-0.9...+13.0	-1.5...+17.7
QZSS	J1-J6	J1-J2	J1-J5
QZO & GEO	-92.0...+5.0	-85.5...+12.0	-80.0...+32.0

Examples for Estimated DCBs

- Differences between DCBs with and without modeled PCOs
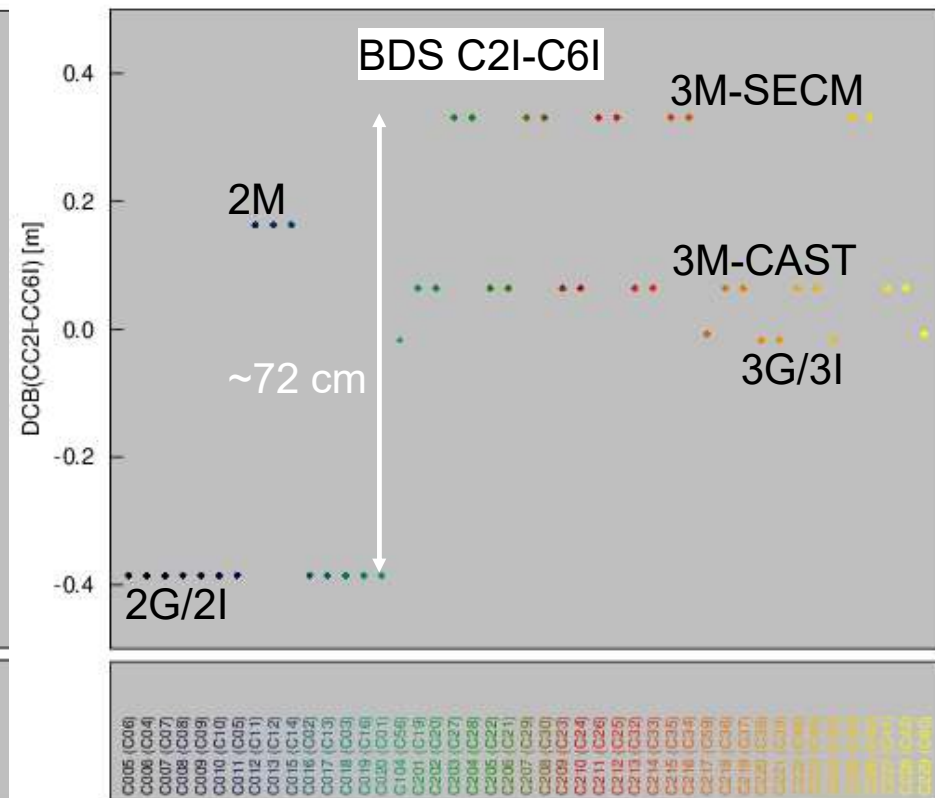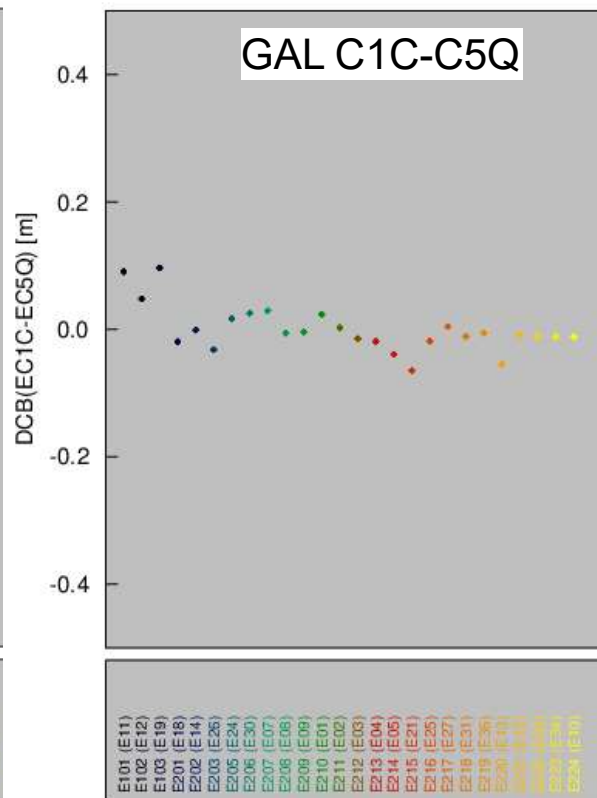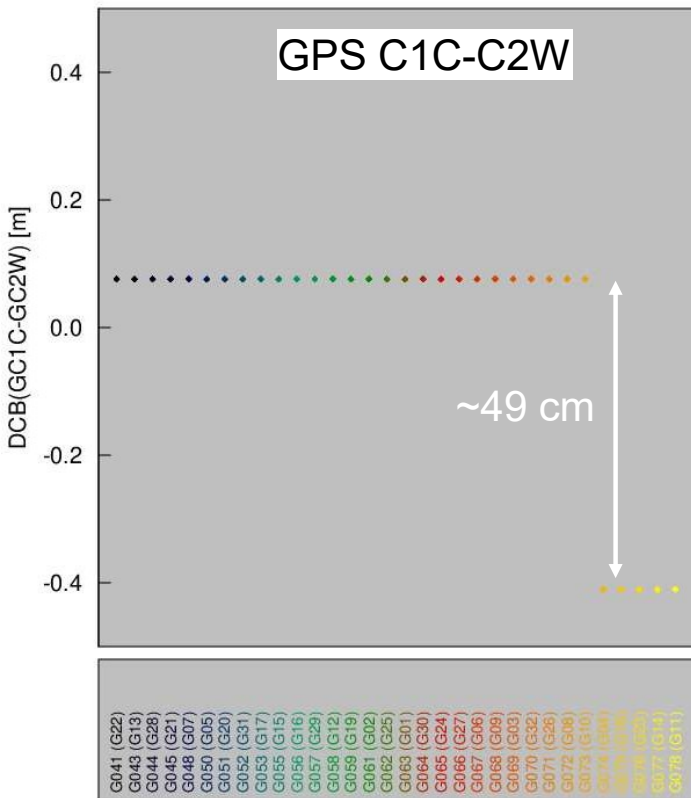
Group-Delay Variations and Other Signal Biases

- BDS-2 Group-Delay Variations

- Patterns depend on frequency and satellite

- No format or convention for GDV modeling
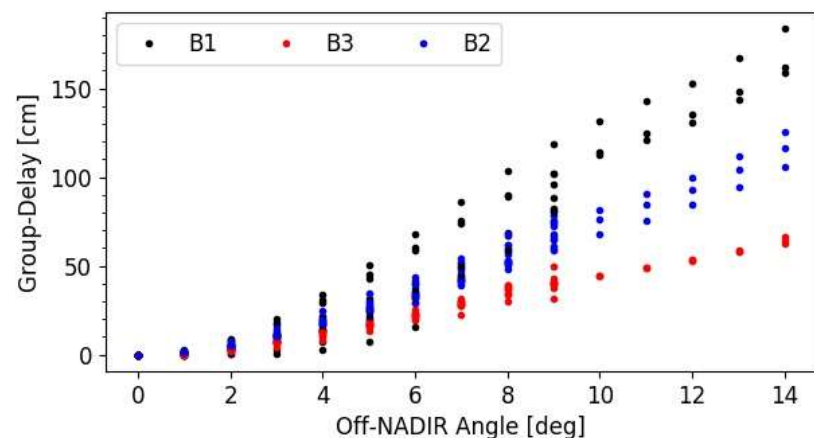
Wanninger L, Beer S (2015) *BeiDou satellite-induced code pseudorange variations: diagnosis and therapy.* GPS Solutions 19(4):639-648. https://doi.org/10.1007/s10291-014-0423-3

- BDS-3 receiver-dependent bias corrections

- Only applied to BDS-3 in mixed BDS-2/-3 processing

- Not absorbed by common BDS-2/-3 receiver DCB

Band	Javad		Trimble		Septentrio	
	Mean	STD	Mean	STD	Mean	STD
B1I	0.01	0.33	0.37	0.45	0.96	0.38
B3I	− 0.41	0.36	− 0.65	0.44	− 0.67	0.37

Zhang Y, Kubo N, Chen J, Chu FJ, Wan A, Wang J (2020) *Apparent clock and TGD biases between BDS-2 and BDS-3.* GPS Solutions 24(27):1521-1886. https://doi.org/10.1007/s10291-019-0933-0

Summary & Recommendations

- Frequency-dependent PCOs in IGS ATX14 affect estimated DCBs

  - Satellite antenna PCO z-offset differences up to several decimeters

  - Station antenna PCO z-offset differences only few centimeters

- GPS III, Galileo, Beidou-2/-3 and QZSS have frequency-dependent PCOs

  - Update values for older GPS satellites or GLONASS in future?

- Consistent modelling between analysis centers and users necessary

  - Analysis centers will switch convention with change to ITRF2020

- Recommendation 1: extend BIAS-SINEX standard by machine-readable indicator for PCO modeling

- Recommendation 2: work towards consistent standard and modeling of group-delay variation patterns