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Biases Relevant to GPS and GLONASS Data Processing

Stefan Schaer

Swiss Federal Office of Topography swisstopo / CODE



List of GNSS biases

- GNSS differential code biases (DCB)
- CODE's DCB specialties (e.g., DCB multiplier estimation)
- GLONASS interfrequency code biases (relevant to GNSS clock estimation, or PPP)
- Intersystem code biases
- “DCPB” crucial for GLONASS ambiguity resolution
- Intersystem phase biases (or drifts)
- Uncalibrated phase delays (UPD) relevant to undifferenced integer fixing for PPP
- GLONASS-GPS station-specific intersystem translations as considered in CODE's GNSS analysis
- IGS ANTEX model: GNSS satellite antenna calibration(s)
- GPS quarter-cycle issue (specifically between L2P and L2C)

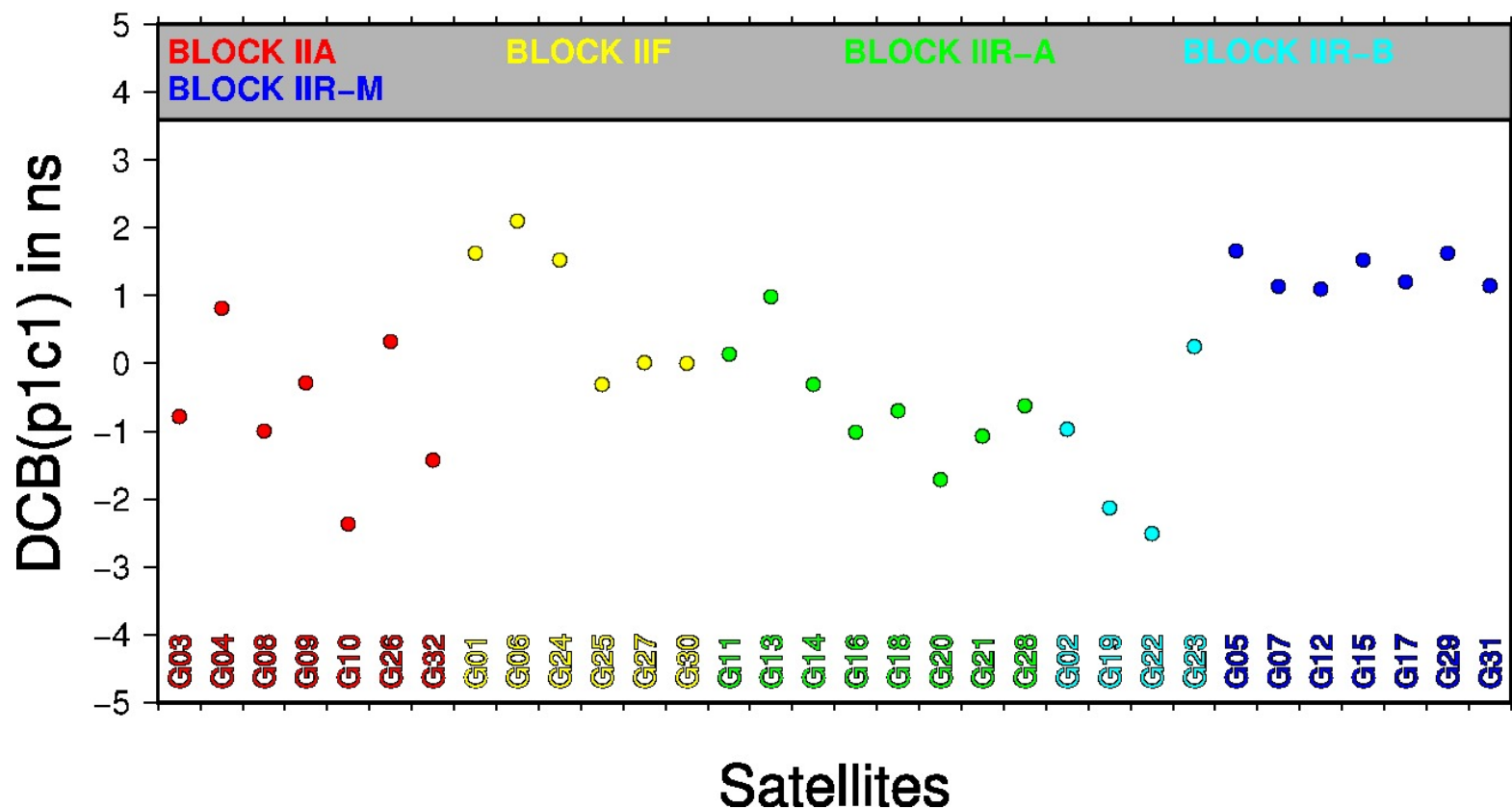


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CODE's GPS P1-C1 DCB (from indirect estimation) as provided to the IGS





Indirect and direct GPS P1-C1 DCB determination (1/3)

GPS receiver classes commonly distinguished:

P1/P2:	C1	P1	P2	
C1/P2:	C1		P2	
C1/X2:	C1			X2



Indirect and direct GPS P1-C1 DCB determination (2/3) → indirect

GPS receiver classes commonly distinguished:

P1/P2:

C1

P1

P2

C1/P2:

C1

P2

C1/X2:

C1

X2



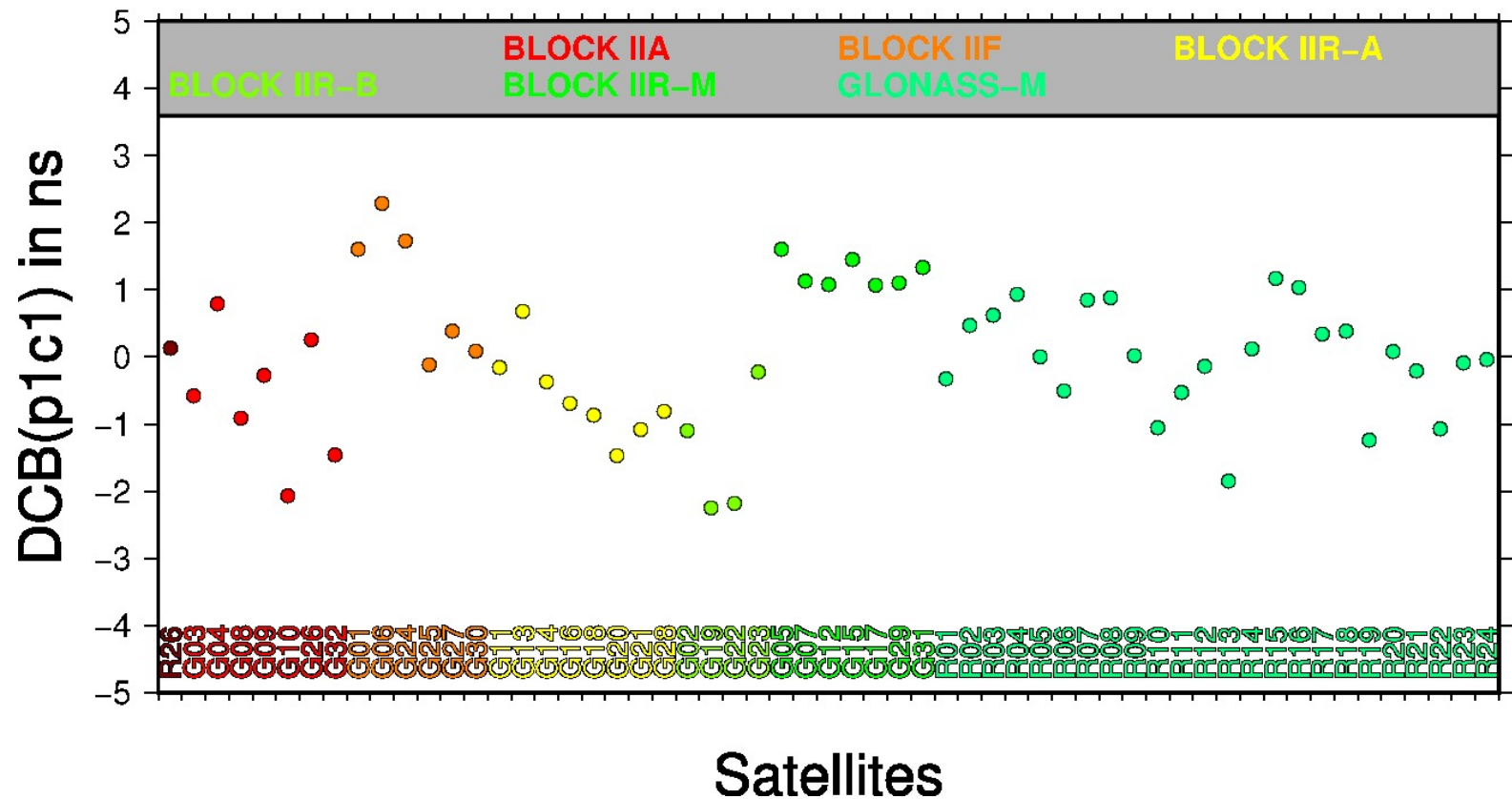
Indirect and direct GPS P1-C1 DCB determination (3/3) → direct

GPS receiver classes commonly distinguished:

P1/P2:	C1	P1	P2
C1/P2:	C1		P2
C1/X2:	C1		X2

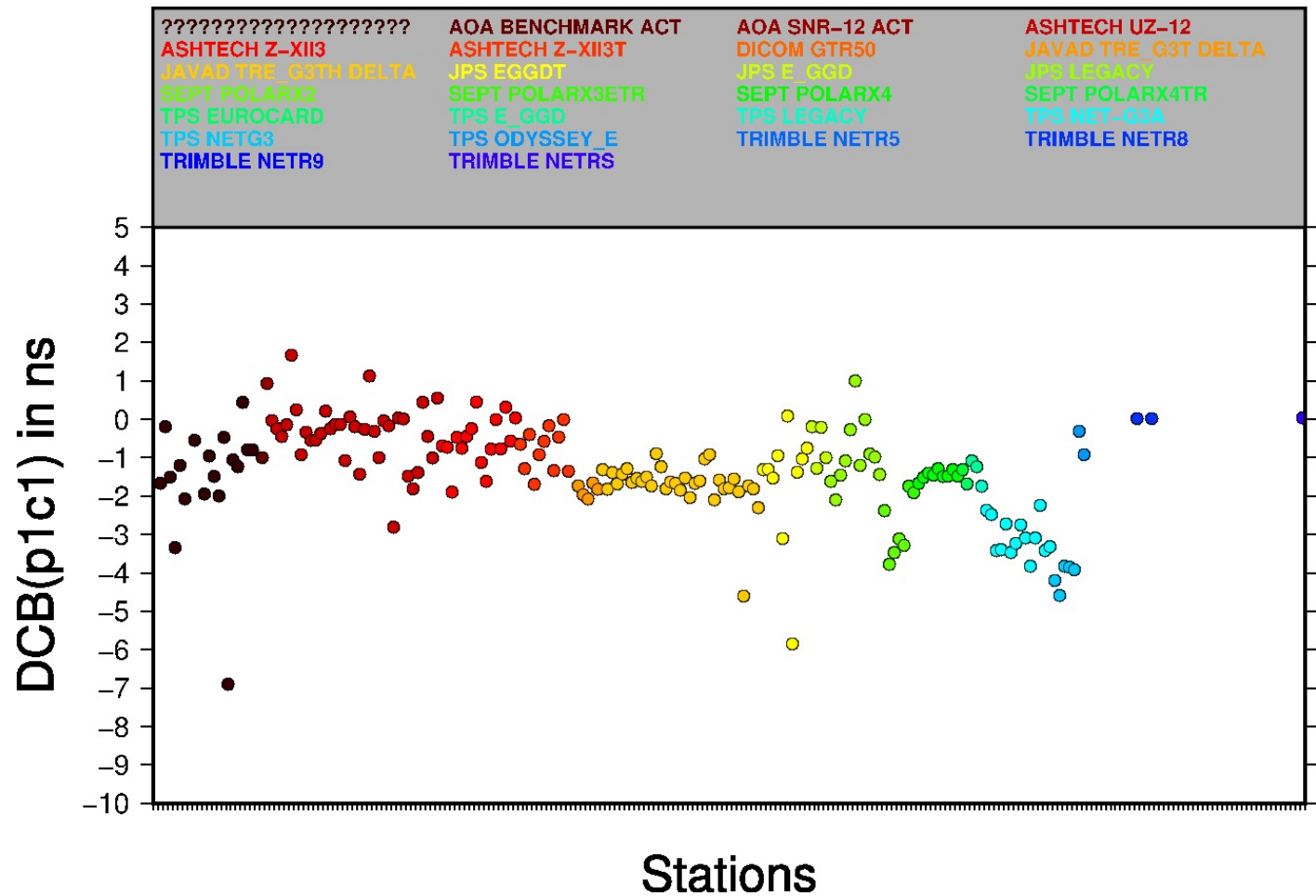


CODE's GPS/GLONASS P1-C1 DCB (from direct estimation) for all available satellites



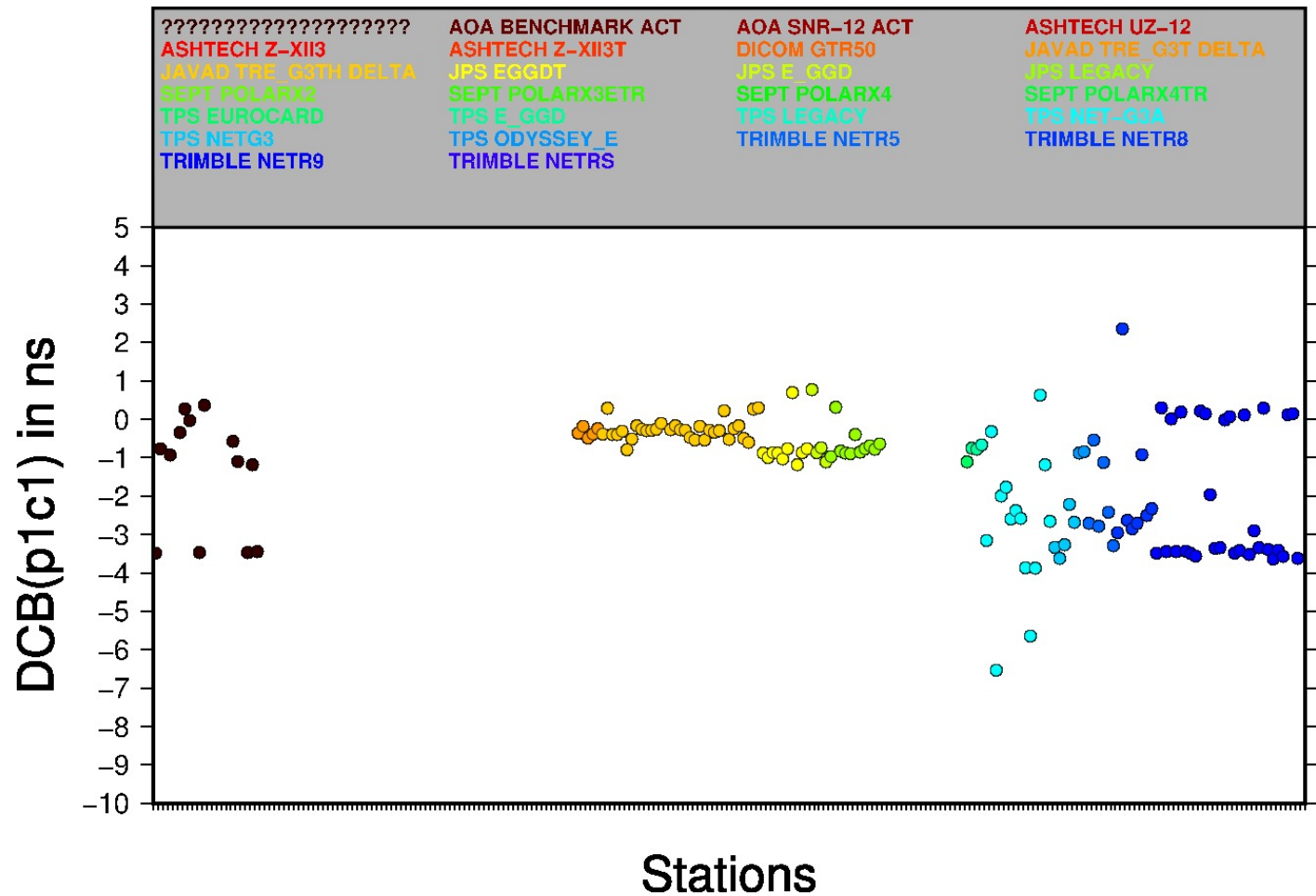


CODE's GPS/GLONASS P1-C1 DCB (from direct estimation) for all involved receivers



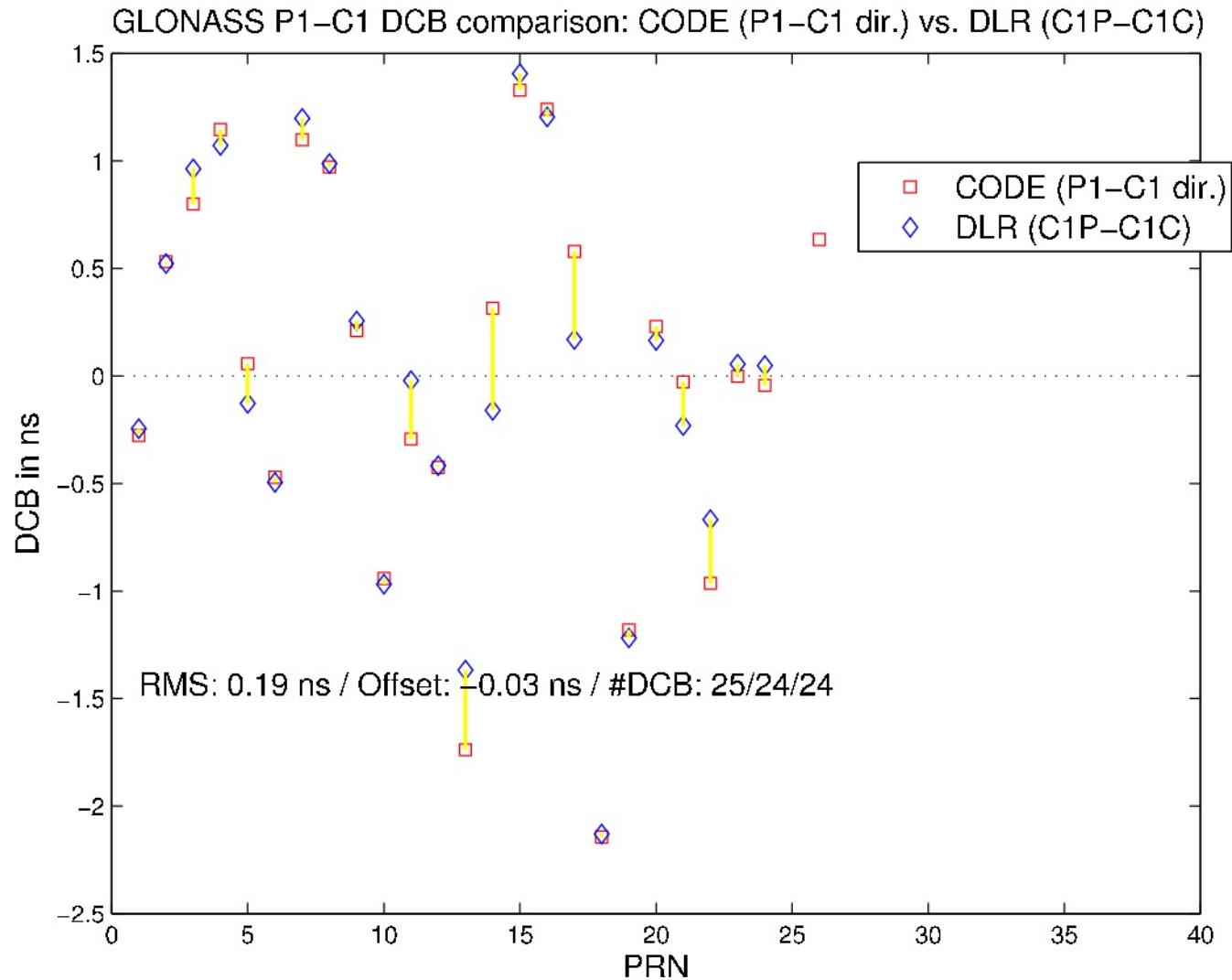


CODE's GPS/GLONASS P1-C1 DCB (from direct estimation) for all involved receivers



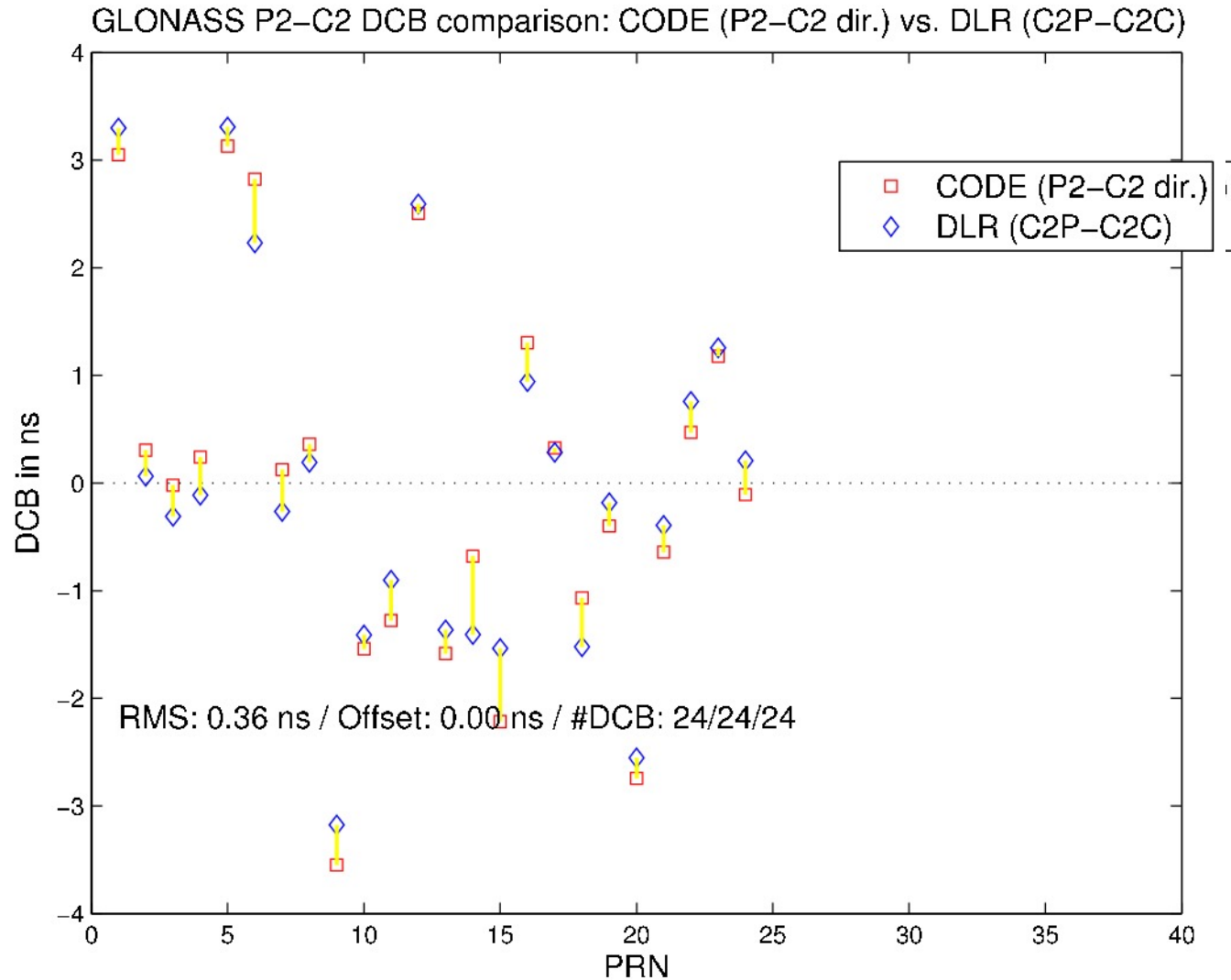


Comparison of GPS/GLONASS P1-C1 DCB results as generated by: CODE and DLR



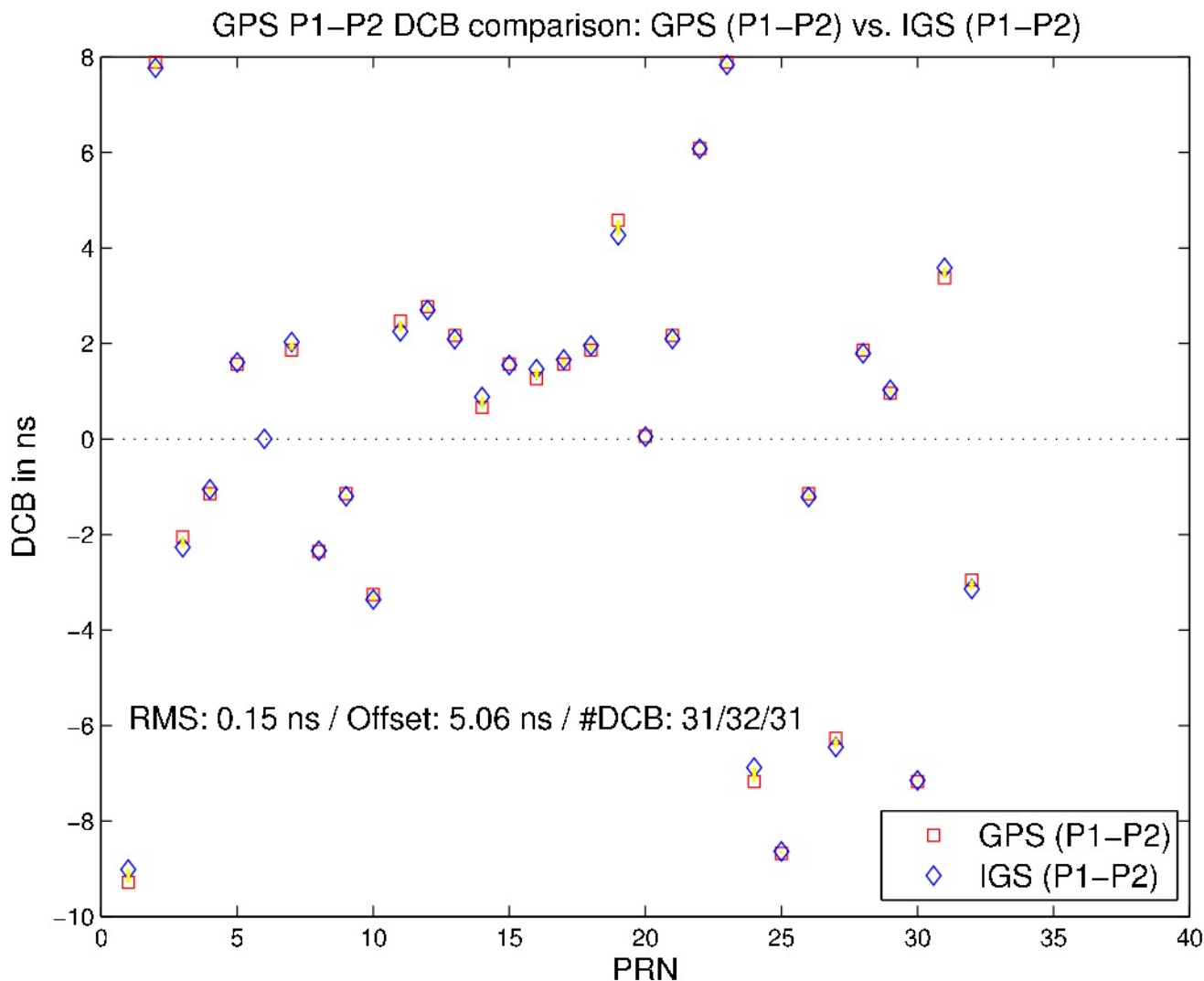


Comparison of GPS/GLONASS P2-C2 DCB results as generated by: CODE and DLR



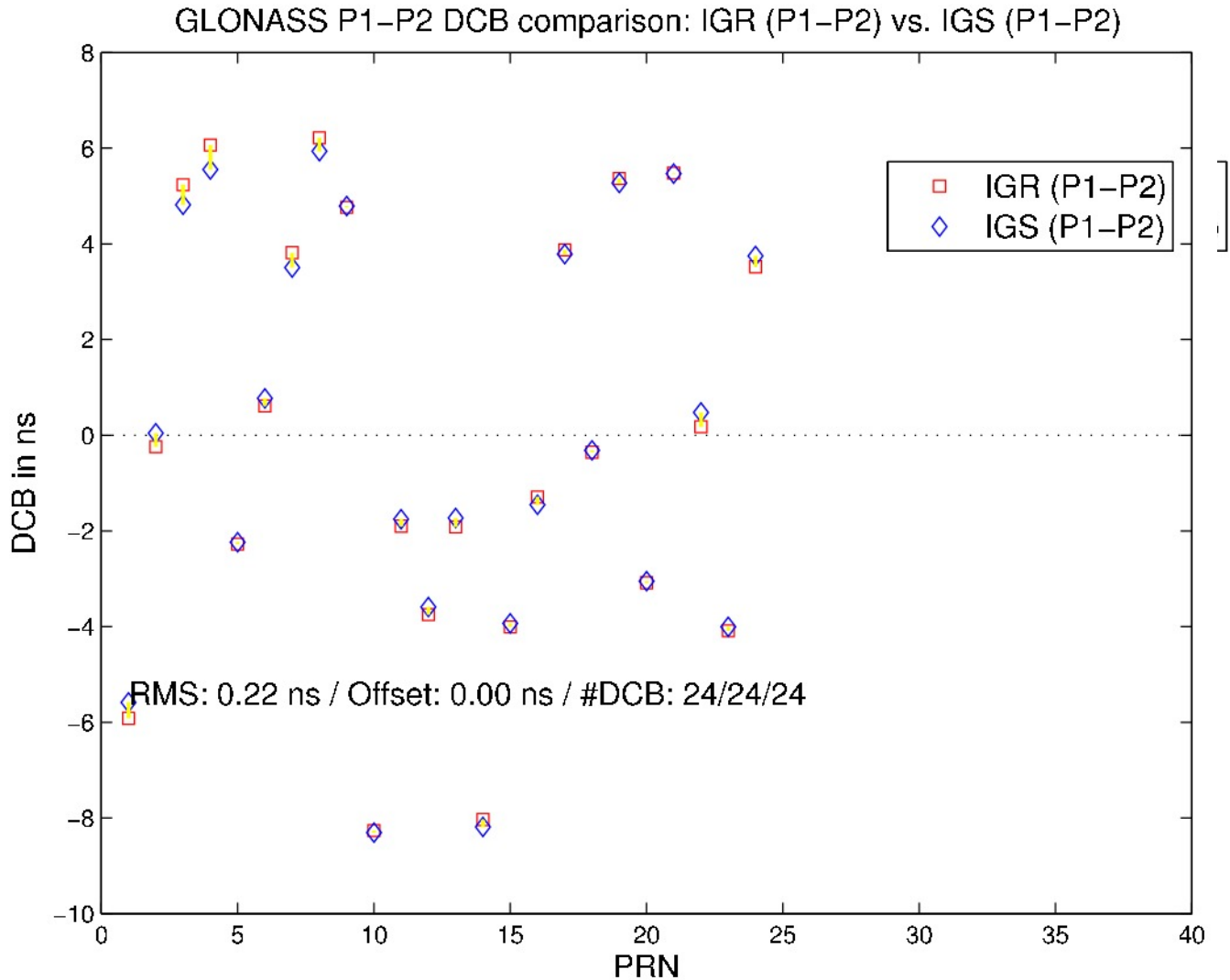


Comparison of GPS/GLONASS P1-P2 DCB results as generated by: CODE, ESA, JPL, DLR, IGS, “GPS”





Comparison of GPS/GLONASS P1-P2 DCB results as generated by: CODE, ESA, DLR, IGS/IGR



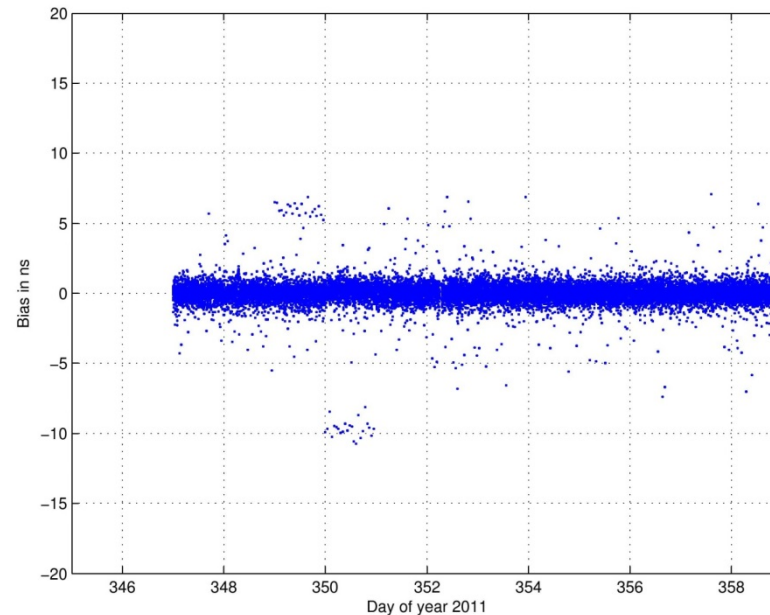


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AC GLONASS bias comparison: COD-ESA

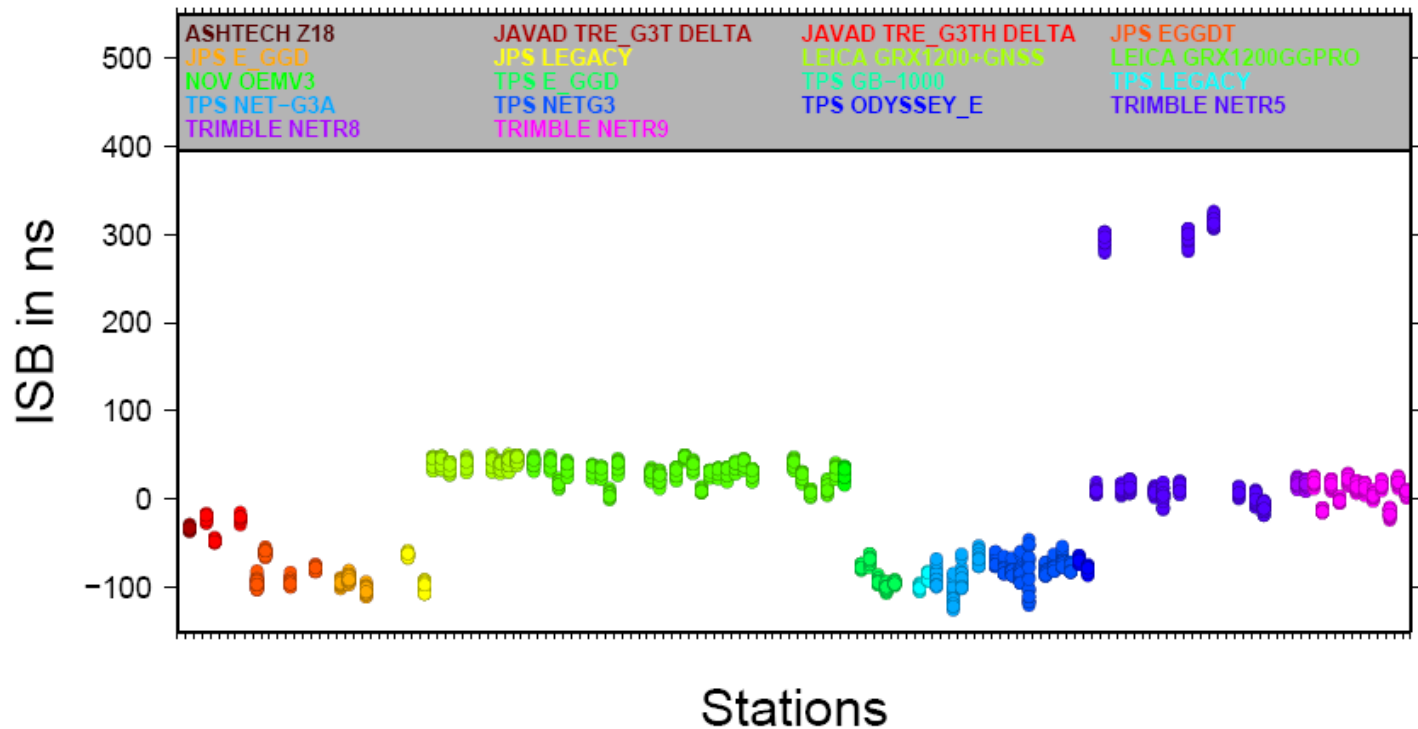


- Best agreement (smallest std) could be achieved for the comparison between COD and ESA
 - with an overall std of 0.79 ns
 - resulting in a single-AC std of 0.56 ns
- Only 24 constants were necessary to compensate for the GLONASS bias datum definition specific to each AC



IFB/ISB Computed by the Analysis Centers

ISB characteristic of the receivers



Analyse centrum: COD

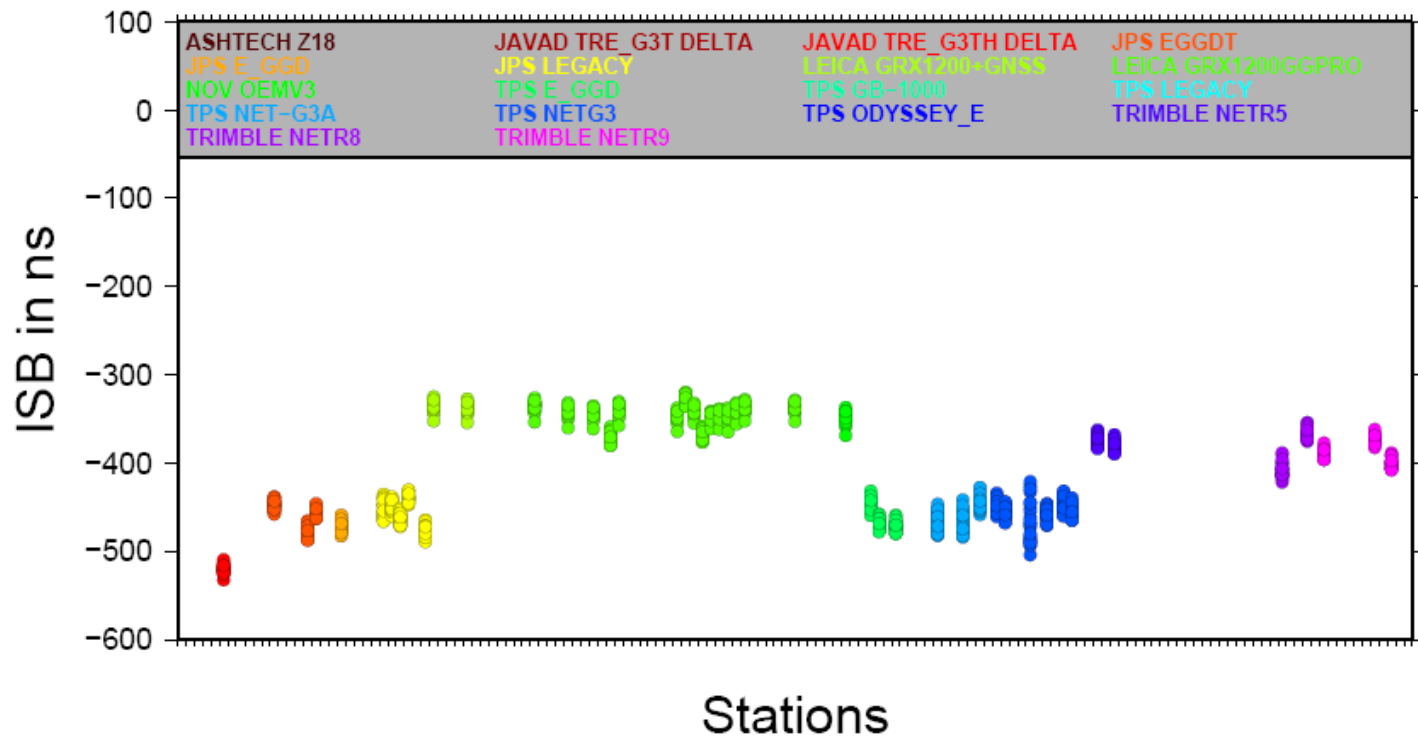
AIUB

Dach, Schaer and Meindl: Comparison of GPS/GLONASS Clock Solution – 20 / 34



IFB/ISB Computed by the Analysis Centers

ISB characteristic of the receivers



Analyse centrum: ESA

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List of GNSS biases

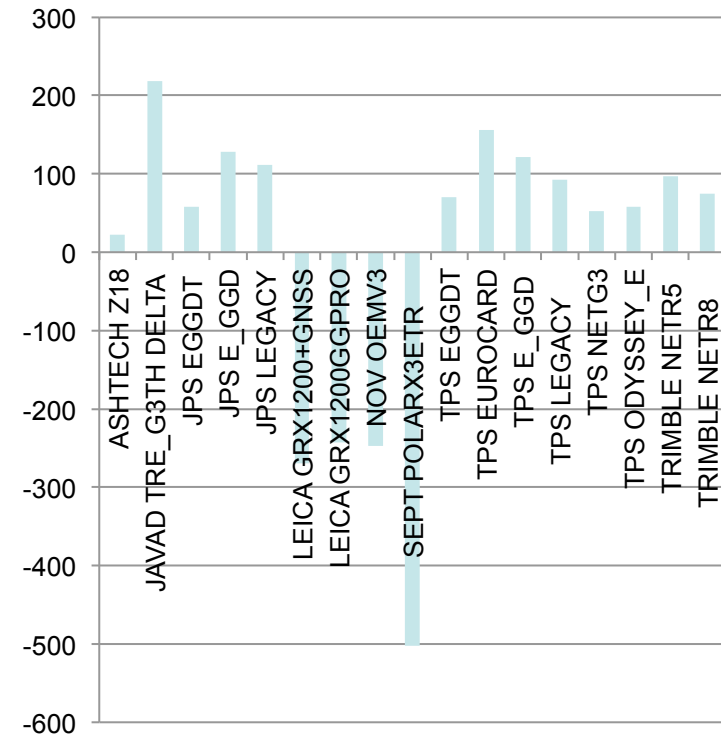
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LS combination of CODE's accumulated IGSFINAL and EPNFINAL SDBysss.LST results (WL) (2012)

Receiver type / SD bias / RMS error (ns)

ASHTECH Z18	:	22.120	2.268
JAVAD TRE_G3TH DELTA	:	218.901	0.675
JPS EGGDT	:	58.271	0.606
JPS E_GGD	:	128.505	0.565
JPS LEGACY	:	111.921	0.609
LEICA GRX1200+GNSS	:	-269.900	0.753
LEICA GRX1200GGPRO	:	-242.546	0.484
NOV OEMV3	:	-247.286	0.516
SEPT POLARX3ETR	:	-501.984	0.533
TPS EGGDT	:	70.275	0.726
TPS EUROCARD	:	155.776	0.652
TPS E_GGD	:	121.529	0.868
TPS LEGACY	:	92.682	0.517
TPS NETG3	:	52.682	0.507
TPS ODYSSEY_E	:	57.586	0.611
TRIMBLE NETR5	:	96.551	0.515
TRIMBLE NETR8	:	74.919	0.908

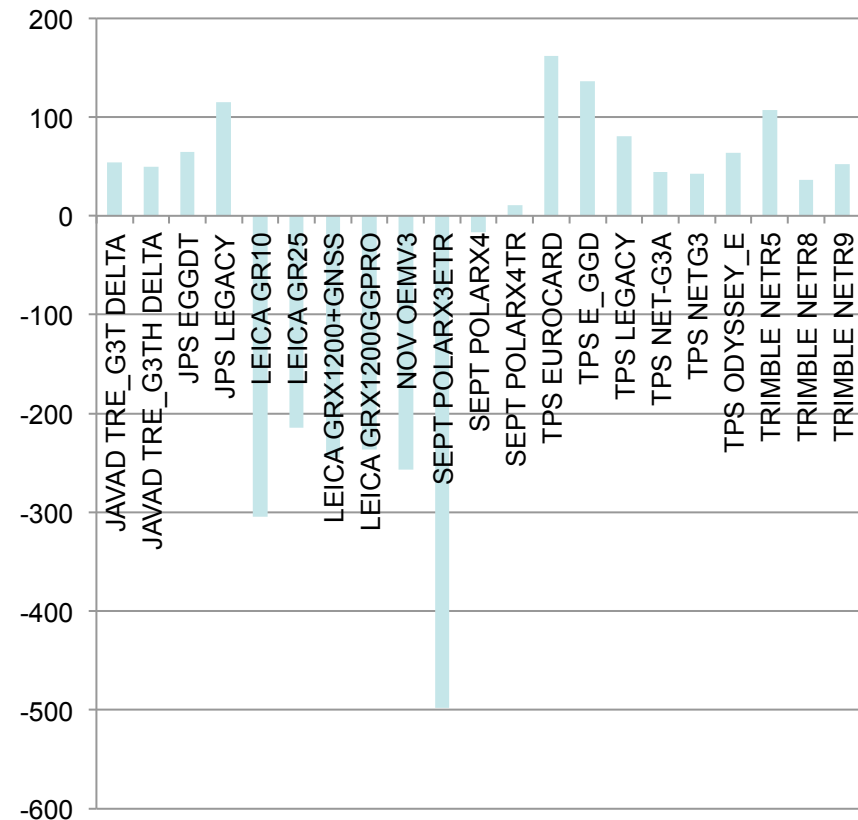




LS combination of CODE's accumulated IGSFINAL and EPNFINAL SDBysss.LST results (WL) (2014)

Receiver type / SD bias / RMS error (ns)

JAVAD TRE_G3T DELTA	:	54.442	2.494
JAVAD TRE_G3TH DELTA	:	49.873	0.432
JPS EGGDT	:	64.743	0.667
JPS E_GGD	:	750.730	1.304
JPS LEGACY	:	115.377	0.673
LEICA GR10	:	-304.067	2.017
LEICA GR25	:	-214.176	0.523
LEICA GRX1200+GNSS	:	-244.674	0.753
LEICA GRX1200GGPRO	:	-236.453	0.844
NOV OEMV3	:	-256.800	0.748
SEPT POLARX3ETR	:	-497.962	0.882
SEPT POLARX4	:	-16.684	0.723
SEPT POLARX4TR	:	10.562	3.411
TPS EUROCARD	:	162.139	0.959
TPS E_GGD	:	136.255	4.202
TPS LEGACY	:	80.854	0.432
TPS NET-G3A	:	43.988	0.524
TPS NETG3	:	42.850	0.432
TPS ODYSSEY_E	:	63.384	0.670
TRIMBLE NETR5	:	107.414	0.540
TRIMBLE NETR8	:	36.115	0.633
TRIMBLE NETR9	:	52.091	0.415



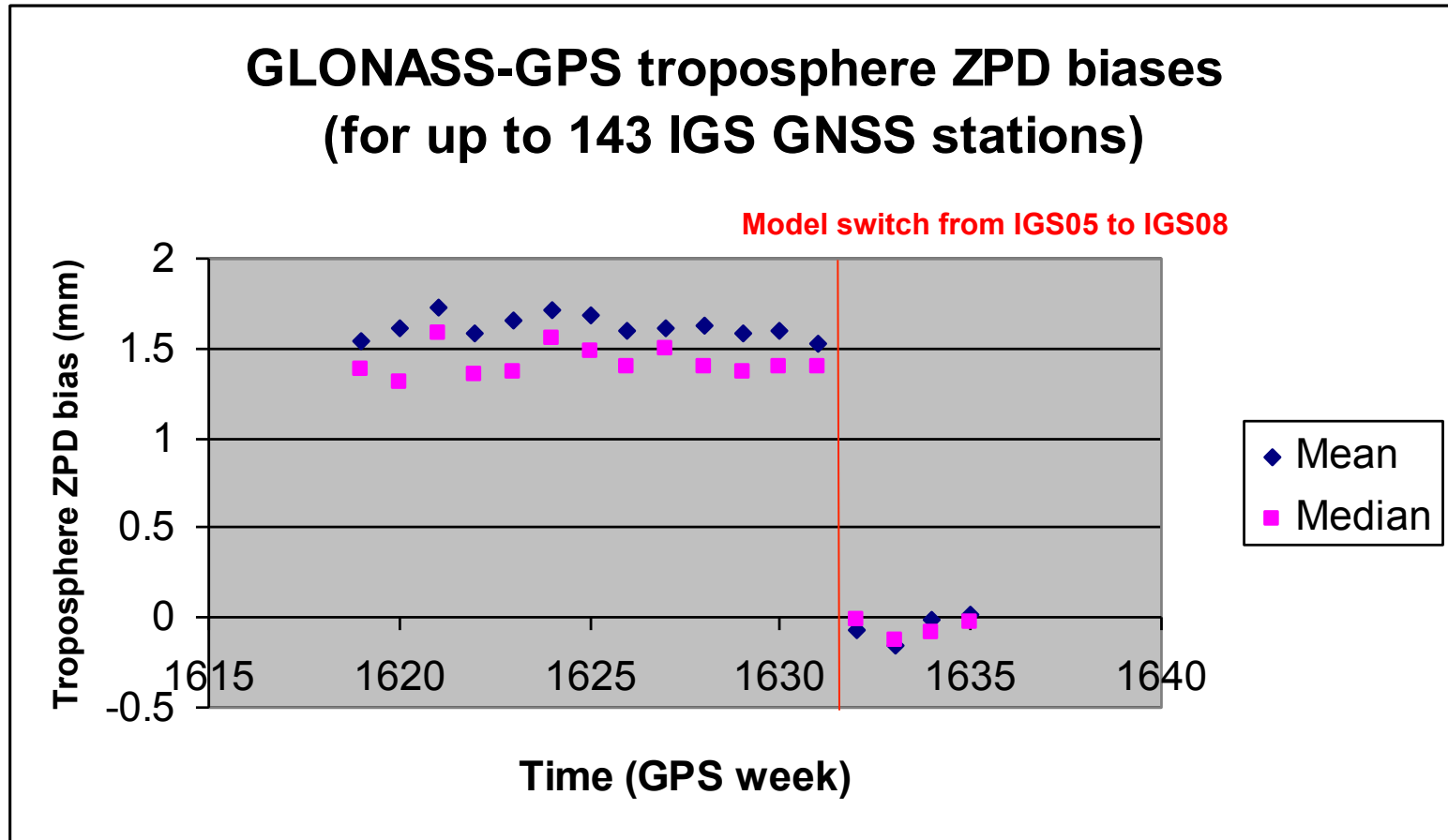


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Mean GLONASS-GPS troposphere ZPD biases: CODE IGS (global) weekly results





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GNSS satellite antenna calibration(s)

- At present, GNSS satellite antenna calibration is just considered with respect the ionosphere-free LC (L_C):
 - $PCV_{L1} = PCV_{L_C}$
 - $PCV_{L2} = PCV_{L_C}$
 - $PCV_{L_C} = 2.55 PCV_{L1} - 1.55 PCV_{L2} = PCV_{L_C}$
- For ionosphere analysis, where commonly the geometry-free, or “ionospheric” LC (L_I) is used, a questionable assumption is made: **$PCV_{L_I} = 0$**
- “ PCV_{L_I} ” must be considered determinable; PCV-dedicated parameters are actually set up in all ionosphere NEQs at CODE.
 - With information on both PCV_{L_C} and PCV_{L_I} , we could specify:
 - $PCV_{L1} = PCV_{L_C} - 1.55 PCV_{L_I}$
 - $PCV_{L2} = PCV_{L_C} - 2.55 PCV_{L_I}$



Summary and outlook (1/3)

- Each GNSS observable is *biased*.
- For high(est)-precision multiple-GNSS applications, the list of relevant biases is already long.
- Handling of biases for GLONASS is (more) demanding (because of FDMA).
- GPS/GLONASS DCB comparisons generally revealed good agreement between our results and DLR's MGEX DCB prototype product (apart from P1-P2 differences).
- Bias SINEX 1.00 to be finalized and adopted by the IGS (BCWG).



Summary and outlook (2/3)

- CODE will start to provide the GPS/GLONASS DCB values in .BIA format as well as in moderately extended Bernese .DCB (with time window info).
- **cc2noncc**, currently maintained by N. Romero, will not to be extended to RINEX-3. Users are encouraged to handle this information in their S/W.
- IGS Bias Workshop 2015 is planned at ESA/ESOC (participation on invitation-only basis).
- See also: www.biasws2012.unibe.ch
- We expect that consideration of station coordinates specific to *each* GNSS will become common.

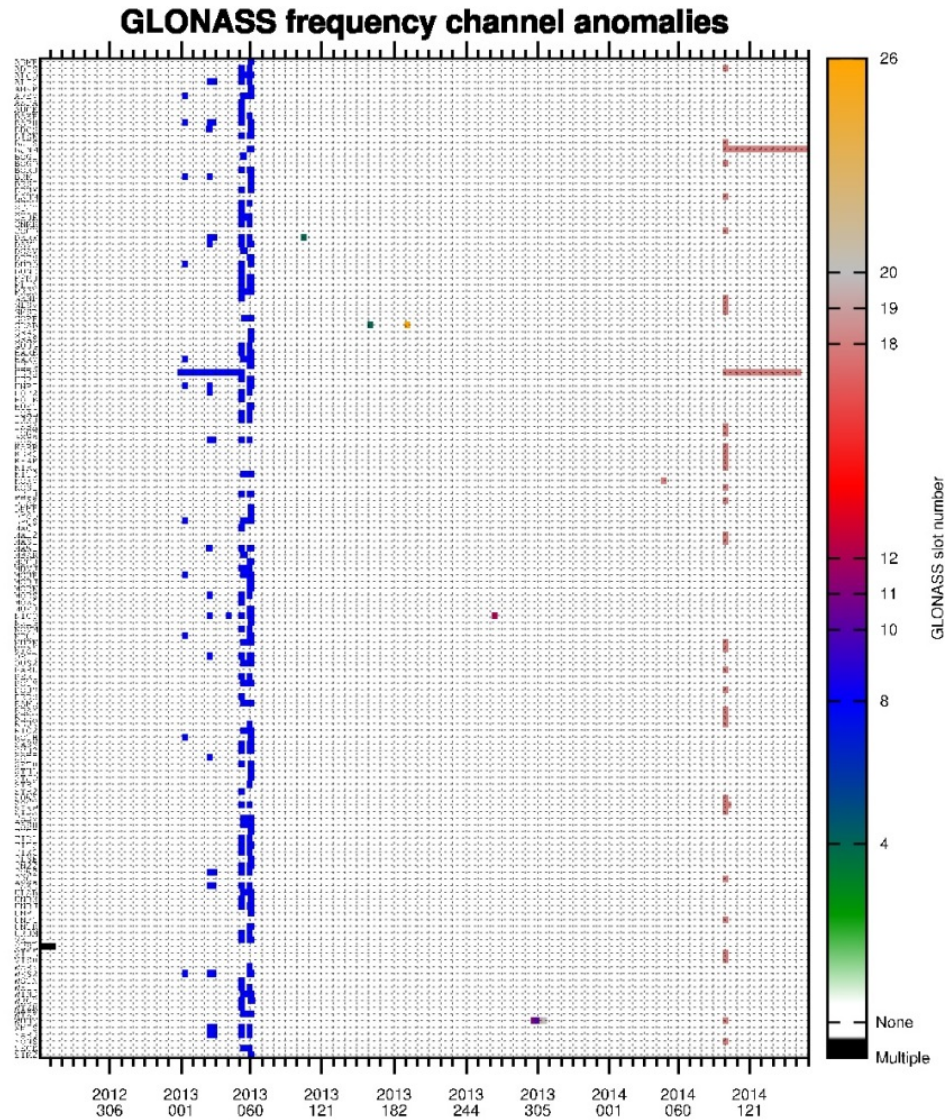


Summary and outlook (3/3)

- From differential (DCB) to “absolute,” or observable(-specific) code bias (ACB, or OCB) values—being consistent with respect to each DCB set and with respect to the “P1/P2” reference convention.



Irregularities in GNSS tracking data





Plethora of GNSS observables: different GPS/GLONASS receiver tracking (1/3)

AOA BENCHMARK ACT	(0.49%)	G:C1	G:P1	G:P2	.	.	.	.
AOA SNR-12 ACT	(0.27%)	G:C1	G:P1	G:P2	.	.	.	.
ASHTECH PF500	(0.27%)	G:C1	.	G:P2	.	R:C1	.	R:P2
ASHTECH UZ-12	(10.60%)	G:C1	G:P1	G:P2	.	.	.	.
ASHTECH Z-XII3	(4.31%)	G:C1	G:P1	G:P2	.	.	.	.
ASHTECH Z-XII3T	(2.92%)	G:C1	G:P1	G:P2	.	.	.	.
DICOM GTR50	(0.26%)	G:C1	G:P1	G:P2	.	.	.	.
JAVAD EGGDT	(0.08%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
JAVAD TRE_G3T DELTA	(1.35%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
JAVAD TRE_G3TH DELTA	(0.13%)	G:C1	G:P1	G:P2	.	.	.	.
JAVAD TRE_G3TH DELTA	(7.92%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
JPS E_GGD	(1.46%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
JPS EGGDT	(2.96%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
JPS LEGACY	(3.26%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
LEICA GR10	(0.19%)	G:C1	.	G:P2	.	.	.	.
LEICA GR10	(0.86%)	G:C1	.	G:P2	.	R:C1	.	R:P2
LEICA GR25	(2.86%)	G:C1	.	G:P2	.	R:C1	.	R:P2
LEICA GRX1200GGPRO	(0.02%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2
LEICA GRX1200GGPRO	(9.80%)	G:C1	.	G:P2	.	R:C1	.	R:P2
LEICA GRX1200+GNSS	(4.74%)	G:C1	.	G:P2	.	R:C1	.	R:P2
LEICA GRX1200PRO	(0.82%)	G:C1	.	G:P2	.	.	.	.
LEICA RS500	(0.25%)	G:C1	.	G:P2	.	.	.	.
NOV OEM4-G2	(0.26%)	G:C1	.	G:P2	.	.	.	.
NOV OEMV3	(0.96%)	G:C1	.	G:P2	.	R:C1	.	R:P2
ROGUE SNR-8000	(0.03%)	G:C1	.	G:P2	.	.	.	.
SEPT POLARX2	(1.83%)	G:C1	G:P1	G:P2	.	.	.	.
SEPT POLARX3ETR	(0.54%)	G:C1	G:P1	G:P2	.	R:C1	.	R:P2
SEPT POLARX4	(0.26%)	G:C1	G:P1	G:P2	.	R:C1	.	R:P2
SEPT POLARX4	(2.40%)	G:C1	G:P1	G:P2	.	R:C1	.	R:P2
SEPT POLARX4	(0.25%)	G:C1	.	G:P2	.	.	.	.
SEPT POLARX4	(0.02%)	G:C1	.	G:P2	.	R:C1	.	R:P2
SEPT POLARX4TR	(0.24%)	G:C1	G:P1	G:P2	.	R:C1	.	R:P2



Plethora of GNSS observables: different GPS/GLONASS receiver tracking (2/3)

TPS E_GGD	(0.17%)	G:C1	G:P1	G:P2	.	.	.	.	.
TPS E_GGD	(0.82%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS E_GGD	(0.27%)	G:C1	.	G:P2	.	R:C1	.	R:P2	.
TPS EUROCARD	(0.27%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS GB-1000	(0.27%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS LEGACY	(0.31%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS NET-G3A	(3.31%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS NET-G3A	(1.05%)	G:C1	.	G:P2	.	.	.	.	.
TPS NETG3	(0.05%)	G:C1	G:P1	G:P2	.	.	.	.	.
TPS NETG3	(1.87%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TPS ODYSSEY_E	(0.79%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TRIMBLE 4000SSI	(1.35%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE 4700	(0.81%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE 5700	(0.53%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE NETR5	(0.05%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE NETR5	(0.25%)	G:C1	.	G:P2	.	R:C1	R:P1	.	.
TRIMBLE NETR5	(2.40%)	G:C1	.	G:P2	.	R:C1	R:P1	R:P2	.
TRIMBLE NETR5	(1.87%)	G:C1	.	G:P2	.	R:C1	.	R:P2	.
TRIMBLE NETR8	(0.54%)	G:C1	G:P1	G:P2	.	R:C1	R:P1	R:P2	.
TRIMBLE NETR8	(0.83%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE NETR8	(0.26%)	G:C1	.	G:P2	.	R:C1	R:P1	.	.
TRIMBLE NETR8	(1.34%)	G:C1	.	G:P2	.	R:C1	R:P1	R:P2	.
TRIMBLE NETR8	(1.34%)	G:C1	.	G:P2	.	R:C1	.	R:P2	.
TRIMBLE NETR9	(1.52%)	G:C1	.	G:P2	.	.	.	.	.
TRIMBLE NETR9	(8.91%)	G:C1	.	G:P2	.	R:C1	R:P1	R:P2	.
TRIMBLE NETR9	(0.25%)	G:C1	.	G:P2	.	R:C1	.	R:P2	.
TRIMBLE NETRS	(0.27%)	G:C1	G:P1	G:P2	.	.	.	.	.
TRIMBLE NETRS	(5.68%)	G:C1	.	G:P2	.	.	.	.	.



Plethora of GNSS observables: different GPS/GLONASS receiver tracking (3/3)

ASHTECH UZ-12	(2)
JAVAD TRE_G3TH DELTA	(2)
LEICA GR10	(2)
LEICA GR25	(2)
LEICA GRX1200GGPRO	(3)
SEPT POLARX4	(4)
TPS E_GGD	(3)
TPS NETG3	(2)
TPS NET-G3A	(2)
TRIMBLE 4000SSI	(2)
TRIMBLE NETR5	(4)
TRIMBLE NETR8	(6)
TRIMBLE NETR9	(4)
TRIMBLE NETRS	(4)



List of GNSS receiver types (40) currently used

AOA BENCHMARK ACT	(0.49%)
AOA SNR-12 ACT	(0.27%)
ASHTECH PF500	(0.27%)
ASHTECH UZ-12	(10.60%)
ASHTECH Z-XII3	(4.31%)
ASHTECH Z-XII3T	(2.92%)
DICOM GTR50	(0.26%)
JAVAD EGGDT	(0.08%)
JAVAD TRE_G3T DELTA	(1.35%)
JAVAD TRE_G3TH DELTA	(8.05%)
JPS E_GGD	(1.46%)
JPS EGGDT	(2.95%)
JPS LEGACY	(3.26%)
LEICA GR10	(1.05%)
LEICA GR25	(2.86%)
LEICA GRX1200GGPRO	(9.82%)
LEICA GRX1200+GNSS	(4.74%)
LEICA GRX1200PRO	(0.82%)
LEICA RS500	(0.25%)
NOV OEM4-G2	(0.26%)
NOV OEMV3	(0.96%)
ROGUE SNR-8000	(0.03%)
SEPT POLARX2	(1.83%)
SEPT POLARX3ETR	(0.54%)
SEPT POLARX4	(2.93%)
SEPT POLARX4TR	(0.24%)
TPS E_GGD	(1.25%)
TPS EUROCARD	(0.27%)
TPS GB-1000	(0.27%)
TPS LEGACY	(0.31%)
TPS NETG3	(1.92%)
TPS NET-G3A	(4.36%)
TPS ODYSSEY_E	(0.79%)
TRIMBLE 4000SSI	(1.36%)
TRIMBLE 4700	(0.81%)
TRIMBLE 5700	(0.53%)
TRIMBLE NETR5	(4.56%)
TRIMBLE NETR8	(4.32%)
TRIMBLE NETR9	(10.68%)
TRIMBLE NETRS	(5.95%)