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Bias handling and ambiguity resolution

Stefan Schaer

swisstopo, Bias and Calibration Working Group Chair, Switzerland

Tour de l'IGS 3rd Stop: GNSS processing based in IGS products

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Outline

- *Code biases* are required for:
  - double-difference widelane AR relying on MW LC
  - clock analysis (using ionosphere-free LC)
  - pseudorange-supported PPP (not for phase-based PPP)
  - ionosphere analysis (using the geometry-free LC)

- *Phase biases* are required for
  - single-receiver AR performed in PPP analysis mode

- Additional remarks

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GPS code observables (L1/L2)

SVN	PRN	Satellite generation								
G041	G22	BLOCK IIR-A	C1C		C1W				C2W	
G043	G13	BLOCK IIR-A	C1C	C1P	C1W				C2W	
G044	G28	BLOCK IIR-A	C1C		C1W				C2W	
G045	G21	BLOCK IIR-A	C1C		C1W				C2W	
G048	G07	BLOCK IIR-M	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G050	G05	BLOCK IIR-M	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G051	G20	BLOCK IIR-A	C1C	C1P	C1W				C2W	
G052	G31	BLOCK IIR-M	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G053	G17	BLOCK IIR-M	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G055	G15	BLOCK IIR-M	C1C		C1W		C2L	C2S	C2W	C2X
G056	G16	BLOCK IIR-A	C1C	C1P	C1W				C2W	
G057	G29	BLOCK IIR-M	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G058	G12	BLOCK IIR-M	C1C		C1W		C2L	C2S	C2W	C2X
G059	G19	BLOCK IIR-B	C1C	C1P	C1W				C2W	
G061	G02	BLOCK IIR-B	C1C	C1P	C1W				C2W	
G062	G25	BLOCK IIF	C1C		C1W		C2L	C2S	C2W	C2X
G063	G01	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G064	G30	BLOCK IIF	C1C		C1W		C2L	C2S	C2W	C2X
G065	G24	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G066	G27	BLOCK IIF	C1C		C1W		C2L	C2S	C2W	C2X
G067	G06	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G068	G09	BLOCK IIF	C1C		C1W		C2L	C2S	C2W	C2X
G069	G03	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G070	G32	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G071	G26	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G072	G08	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G073	G10	BLOCK IIF	C1C	C1P	C1W		C2L	C2S	C2W	C2X
G074	G04	BLOCK IIIA	C1C		C1W	C1X	C2L	C2S	C2W	C2X
G075	G18	BLOCK IIIA	C1C	C1P	C1W	C1X	C2L	C2S	C2W	C2X
G076	G23	BLOCK IIIA	C1C	C1P	C1W	C1X	C2L	C2S	C2W	C2X
G077	G14	BLOCK IIIA	C1C		C1W	C1X	C2L	C2S	C2W	C2X
G078	G11	BLOCK IIIA	C1C	C1P	C1W	C1X	C2L	C2S	C2W	C2X

Introduction

- Due to the satellite (and receiver) hardware, pseudorange measurements recorded in different tracking modes show systematic deviations among each other.
- Corresponding biases cannot be determined in the absolute sense.
- There is a 1:1 dependency of these biases with clock parameters.
- For this reason, the following convention has been agreed upon concerning GPS clock corrections:
  - the ionosphere-free LC of C1W/C2W is assumed to be "unbiased"
- Other types of pseudorange measurements are corrected accordingly, e.g., as follows:

  $$\text{"C1W"} = C1C + B_{C1W-C1C} = C1C + (B_{C1W} - B_{C1C}) = C1C - B_{C1C} + B_{C1W}$$
- Example illustrating OSB (observable-specific signal bias) values:

```
OSB  G063 G01          C1C     2022:015:00000 2022:045:00000 ns           9.3479     0.0077
OSB  G063 G01          C1W     2022:015:00000 2022:045:00000 ns          10.8051     0.0034
OSB  G063 G01          C2W     2022:015:00000 2022:045:00000 ns          17.7955     0.0042
```

- Reference: Villiger et al. 2019: *Determination of GNSS pseudo-absolute code biases and their long-term combination*. Journal of Geodesy, Vol. 93 (9). https://doi.org/10.1007/s00190-019-01262-w

Code bias products

- Inter-frequency DCB values derived by ionosphere analysis centers:
  https://cddis.nasa.gov/archive/gnss/products/ionosphere/
  https://cddis.nasa.gov/archive/gnss/products/ionex/

- GPS C1W and C1C reference values computed at the Center for Orbit Determination in Europe (CODE):
  https://cddis.nasa.gov/archive/gnss/products/bias/code.bia
  https://cddis.nasa.gov/archive/gnss/products/bias/code_monthly.bia

- As part of the IGS *Multi-GNSS Extension (MGEX)* two different DCB products are determined by two analysis groups: Institute of Geodesy and Geophysics (IGG) of the Chinese Academy of Sciences (CAS) in Wuhan and the Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) in Germany. See also:
  https://igs.org/products/#differential_code_bias
  https://cddis.nasa.gov/archive/gnss/products/bias/

- Code/phase bias products accompanying the individual clock products generated by IGS analysis centers:
  https://cddis.nasa.gov/archive/gnss/products/

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Phase bias products

Phase bias product provider	Rapid	Final	MGEX	Repro3	Real time
Center for Orbit Determination in Europe (CODE) [COD]	X	X	X	X	
Natural Resources Canada (NRCan) [EMR]				X	
German Research Center for Geosciences (GFZ) [GFZ]			X		
Centre National d'Etudes Spatiales (CNES) / Collecte Localisation Satellites (CLS) [GRG]		X	X	X	
Graz University of Technology [TUG]				X	
Centre National d'Etudes Spatiales (CNES) / Navigation Team	X				X
Wuhan University [WUM]			X		

Courtesy of: https://igs.org/wg/precise-point-positioning-ppp/#products

Usage of Bias-SINEX for the OSB-based PPP-AR application

The interested PPP-AR user has to comply with the following rules:

1. GNSS orbits and IAR-enabled clocks (Clock-RINEX) have to be used in conjunction with accompanying biases (Bias-SINEX).
2. Such a bias file should contain OSB data records for
   a. *pseudorange code* and
   b. *carrier phase* observations

   that are consistent with the associated (ambiguity-fixed) clock product and, furthermore, have to be applied to each involved observation, specifically in the sense

   $$O_{\text{measured}} = O_{\text{computed}} + B_{\text{satellite}}$$

   or alternatively, depending on the users' preference,

   $$O_{\text{measured}} - B_{\text{satellite}} = O_{\text{computed}}$$

   where *O* stands for observation and *B* for bias. OSB data records are generally labeled with 3-figure observation codes (e. g., C1W, C2W, L1W, L2W, etc. for GPS) as defined in the RINEX3 standard.
3. Following this convention, the users' PPP software should finally be able to recover the integer nature of single-receiver between-satellite phase ambiguities automatically for both
   i. *widelane* ambiguities using the Melbourne-Wübbena LC and subsequently for
   ii. *narrowlane* ambiguities using the ionosphere-free LC (when reintroducing/fixing the previously resolved widelane integers).

Satellites for which phase bias data is unavailable should be suspended for AR, following the **"No phase bias, no AR"** rule (a basic rule we consider appropriate).

For more details, see: https://link.springer.com/article/10.1007/s00190-021-01521-9#appendices

Excerpt from a sample file with code and phase biases that enable PPP-AR

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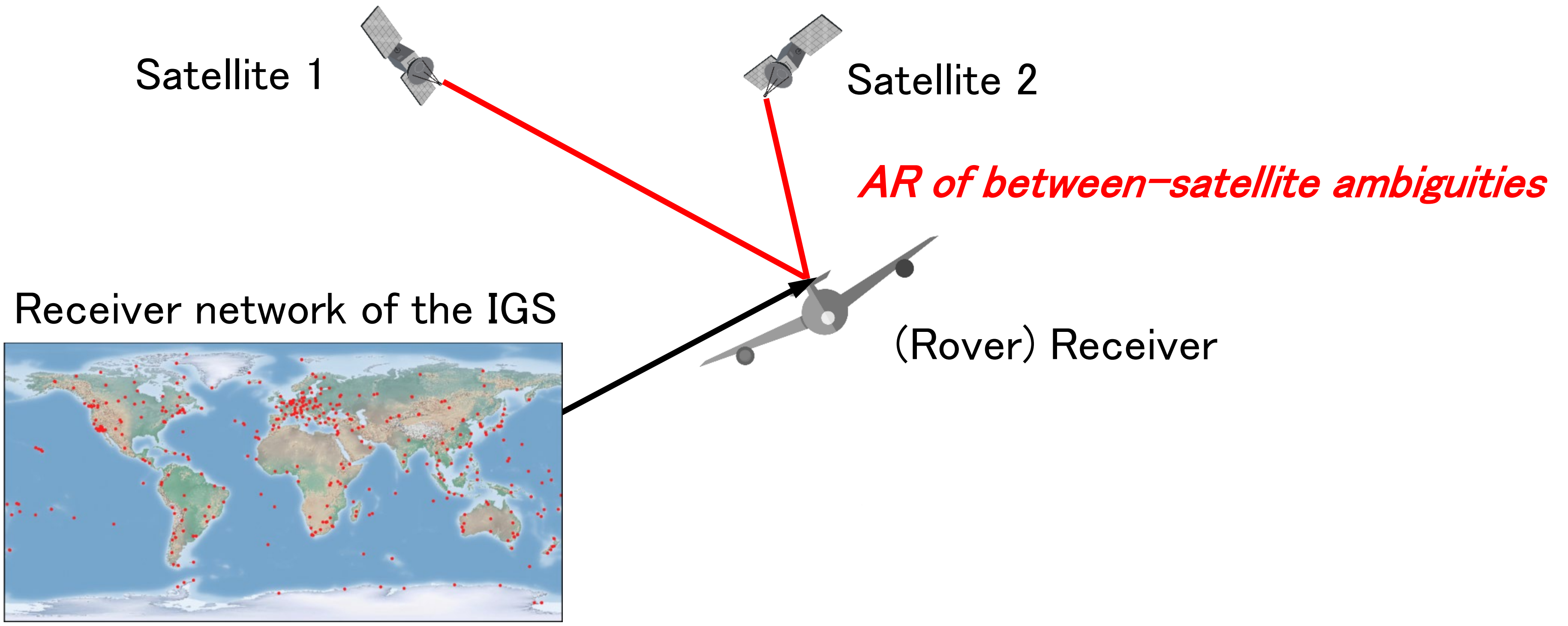
GPS L1/L2	Code biases	OSB	G076	G23	C1C	2022:044:00000	2022:045:00000	ns	-3.6658	0.0037
		OSB	G076	G23	C1X	2022:044:00000	2022:045:00000	ns	-2.9301	0.0205
		OSB	G076	G23	C1W	2022:044:00000	2022:045:00000	ns	-2.9286	0.0000
		OSB	G076	G23	C2L	2022:044:00000	2022:045:00000	ns	-5.3845	0.0106
		OSB	G076	G23	C2S	2022:044:00000	2022:045:00000	ns	-5.4416	0.0094
		OSB	G076	G23	C2X	2022:044:00000	2022:045:00000	ns	-5.1486	0.0147
		OSB	G076	G23	C2W	2022:044:00000	2022:045:00000	ns	-4.8233	0.0000
	Phase biases	OSB	G076	G23	L1C	2022:044:00000	2022:045:00000	ns	-0.03852	0.00000
		OSB	G076	G23	L1L	2022:044:00000	2022:045:00000	ns	-0.03852	0.00000
		OSB	G076	G23	L1X	2022:044:00000	2022:045:00000	ns	-0.03852	0.00000
		OSB	G076	G23	L1W	2022:044:00000	2022:045:00000	ns	-0.03852	0.00000
		OSB	G076	G23	L2L	2022:044:00000	2022:045:00000	ns	0.01413	0.00000
		OSB	G076	G23	L2S	2022:044:00000	2022:045:00000	ns	0.01413	0.00000
		OSB	G076	G23	L2X	2022:044:00000	2022:045:00000	ns	0.01413	0.00000
		OSB	G076	G23	L2W	2022:044:00000	2022:045:00000	ns	0.01413	0.00000
Galileo L1/L5	Code	OSB	E222	E33	C1C	2022:044:00000	2022:045:00000	ns	-2.7349	0.0000
		OSB	E222	E33	C1X	2022:044:00000	2022:045:00000	ns	-2.7366	0.0101
		OSB	E222	E33	C5Q	2022:044:00000	2022:045:00000	ns	-4.9044	0.0000
		OSB	E222	E33	C5X	2022:044:00000	2022:045:00000	ns	-4.8915	0.0101
	Phase	OSB	E222	E33	L1C	2022:044:00000	2022:045:00000	ns	0.27243	0.00000
		OSB	E222	E33	L1X	2022:044:00000	2022:045:00000	ns	0.27243	0.00000
		OSB	E222	E33	L5Q	2022:044:00000	2022:045:00000	ns	0.53244	0.00000
		OSB	E222	E33	L5X	2022:044:00000	2022:045:00000	ns	0.53244	0.00000

PPP with Ambiguity Resolution



Geodetic datum: ITRF(2014)

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Remark on PCO correction convention

- Satellite antenna phase center offset (PCO) values for the GPS Block IIIA and the Galileo satellites differ between the different frequencies:
  - approx. 0.49 m for GPS L1-L2
- Two conventions are currently used for the application of the PC correction (PCC) to the Melbourne-Wübbena linear combination.
- PPP-AR product providers are encouraged to specify the convention used:

```
*-------------------------------------------------------------------------------
+BIAS/DESCRIPTION
*KEYWORD________________________________ VALUE(S)______________________________
 OBSERVATION_SAMPLING                        300
 PARAMETER_SPACING                         86400
 DETERMINATION_METHOD                    CLOCK_ANALYSIS
 BIAS_MODE                               ABSOLUTE
 TIME_SYSTEM                             G
 RECEIVER_CLOCK_REFERENCE_GNSS           G
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES   G  C1W  C2W
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES   R
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES   E  C1C  C5Q
*SATELLITE_ANTENNA_PCC_APPLIED_TO_MW_LC  NO
-BIAS/DESCRIPTION
*-------------------------------------------------------------------------------
```

- See [IGSMAIL-8113] Upcoming convention regarding PCO and biases: https://lists.igs.org/pipermail/igsmail/2021/008109.html

Remark on CODE DCB products made available in other formats

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- CODE (P1-C1) bias products are traditionally also provided in other formats, formats that are now no longer up to date:
  - Bernese DCB (specifically P1C1.DCB, or CODE.DCB): http://ftp.aiub.unibe.ch/CODE/
  - CC2NONCC p1c1bias files: http://ftp.aiub.unibe.ch/bcwg/cc2noncc/
- We would like to announce here in advance that we will discontinue this service as of the transition to ITRF2020 (which is expected in mid-2022).
- Most recent GPS (G22) constellation change (excerpt from CODE.BIA):

```
OSB  G041 G22           C1C     2022:024:00000 2022:045:00000 ns           -1.8992      0.0080
OSB  G041 G22           C1W     2022:024:00000 2022:045:00000 ns           -2.3845      0.0037
OSB  G041 G22           C2W     2022:024:00000 2022:045:00000 ns           -3.9272      0.0048
OSB  G047 G22           C1C     2022:015:00000 2022:019:00000 ns           -8.7291      0.0116
OSB  G047 G22           C1W     2022:015:00000 2022:019:00000 ns          -11.3430      0.0066
OSB  G047 G22           C2W     2022:015:00000 2022:019:00000 ns          -18.6813      0.0103
```

Summary

- Code biases are essential for widelane AR (namely for DD and ZD). We are clearly moving from a differential (DCB, or DSB) to a pseudo-absolute (observable-specific) signal bias (OSB) representation, which shows its advantages regarding multi-GNSS (due to the multitude of different observation types and tracking modes).

- Phase biases, along with code biases, enable single-receiver ambiguity resolution (or briefly PPP-AR). The provision of such biases in OSB form conforming to Bias-SINEX seems to be becoming more and more established within the IGS.

- Bias-SINEX V1.00 data format is approved by the IGS and already widely used.

- **Consistency**, in terms of the products considered and their use, is indispensable. In particular, PPP-AR allows absolutely no discrepancies in this regard, as it is extremely sensitive to this.