ESA Code Bias Reference Frame

Volker Mayer[2], Tim Springer[3], Francesco Gini[1], Frank Zimmermann[1], Erik Schönemann[1]

[1] ESA/ESOC, Darmstadt, Germany
[2] SSC Space GmbH for ESA, Navigation Support Office
[3] PosiTim UG for ESA, Navigation Support Office

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Introduction

- The GNSS environment is growing, providing an increased signal diversity.
  - Signal interoperability between signals is key for optimised usage.
  - A key challenge are hardware-induced delays, such as **Differential Code Biases (DCBs)**.
- DCBs must be estimated and monitored.
  - Availability of published calibration information is very limited.
  - Occasionally affected by in-flight readjustment of satellite hardware
- ESA established the ESA Code Bias Reference Frame.
  - Long-term satellite DCB estimates from 2017
  - BIAS SINEX format
  - Stabilisation of estimation routines and provision of consistent DCB information for user applications
  - The new product is publicly available:
    - https://navigation-office.esa.int/products/gnss-products/ESA0OPSFIN_DCB.BIA

Motivation

ESA Navigation Support Office use-cases

1. Datum definition of daily DCB estimation routines
    - Minimise day-to-day variations
    - Simplify comparison against other AC solution
    - Consider satellite bias calibrations as initial starting point
2. Monitoring of related delays broadcasted by satellites
3. Enable signal combination in PNT applications
    - ESA AC products (P1C1): GPS C1C → C1W
    - Copernicus Sentinel POD: GPS C2L → C2W
4. Generate phase biases products compatible with other signals as used for their estimation.
    - By applying code biases on observations before
    - Code biases with ionosphere-free linear combination equal to zero for each satellite

Galileo FOC

Signal Components

- GNSS signals often consist of a Data and a Pilot component:
  - Data component is navigation-message modulated.
  - Pilot component is unmodulated yielding a lower noise level.

- Components can be tracked individual or jointly (providing the X component).

- Past ESA analysis suggested that identical signal delays for data and pilot components can be assumed.
  - Estimating a single code bias per signal is sufficient.

	Frequencies	Component	Equal to
Galileo	L1, L6	B,C,X	C
	L5, L7, L8	I,Q,X	Q
GPS	L1, L2	P	W
	L1, L2	S,L,X	L
	L5	I,Q,X	Q
BeiDou	L1, L5, L8	D,P,X	P
	L7	D,P,Z	D
QZSS	L1, L2, L6	S,L,X	L
	L5	I,Q,X	Q
	L5s	D,P,Z	P
	L8	D,P,X	X
GLONASS	L3	I,Q,X	Q

The ESA Bias Reference Frame (BREF)

Ionosphere Model	• Estimate Global Ionosphere Model
DCB Estimation	• Generate daily estimates of all the (19) DCBs
DCB Stacking	• Long-term stacking of all the (19) DCBs • Automatic detection of discontinuities
ESA DCB BREF	• Merge all (19) DCBs in one single bias-SINEX file • Add C1C-C1W code bias

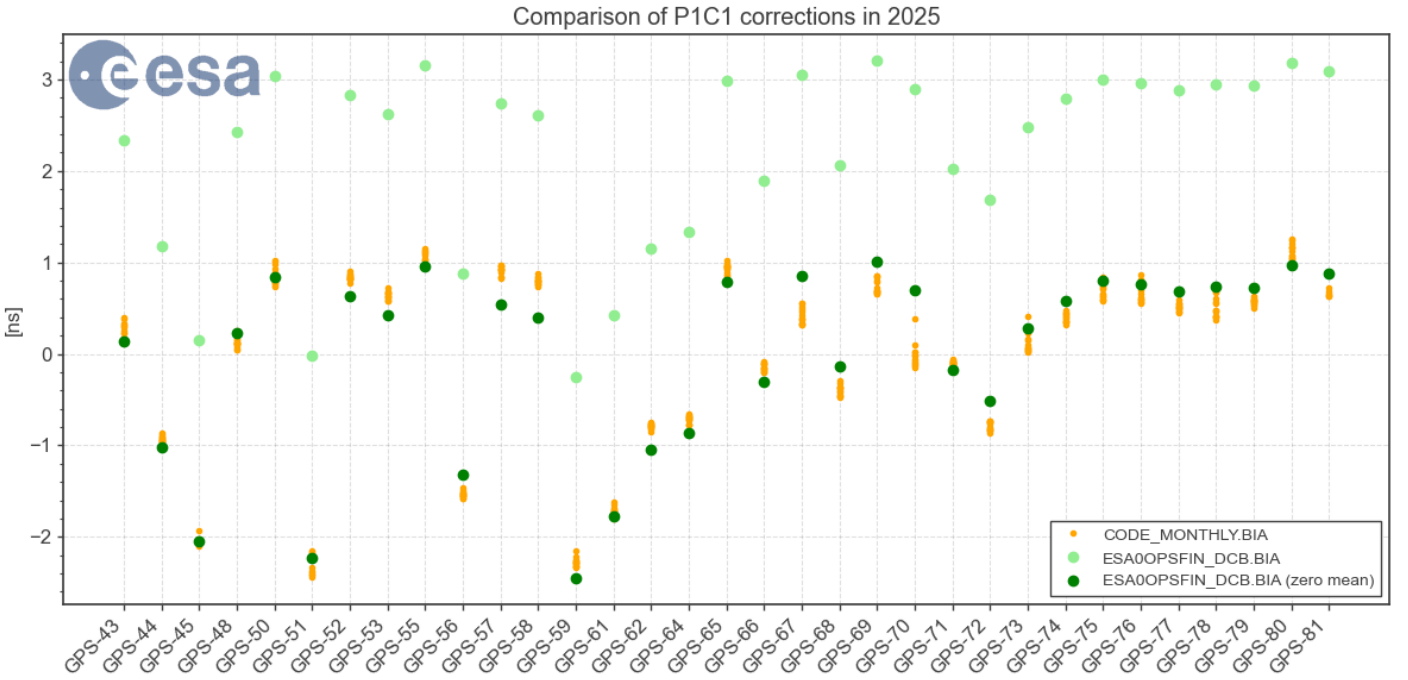
Preview

```
%=BIA 1.00 ESA 2026:078:49431 IGS 2017:001:00000 2026:078:00000 R 00000629
*-------------------------------------------------------------------------------
* Bias Solution INdependent EXchange Format (Bias-SINEX)
*-------------------------------------------------------------------------------
+FILE/REFERENCE
 DESCRIPTION        European Space Operations Centre(ESOC)
 INPUT              CHAMP MGNSS DCBIAS estimates in normal equation format
 OUTPUT             MGNSS DCB estimates in BIAS SINEX format
 CONTACT            Navigation-Office@esa.int
 HARDWARE           SLES15
 SOFTWARE           EPNS 1.3 02/07/2025
-FILE/REFERENCE
*-------------------------------------------------------------------------------
+FILE/COMMENT
 Products available from:
   https://navigation-office.esa.int
 The following signals are considered equal
  - GPS P     equal to W for L1, L2
        S/L/X equal to L for L1, L2
        I/Q/X equal to Q for L5
  - GLO I/Q/X equal to Q for L3
  - GAL B/C/X equal to C for L1, L6
        I/Q/X equal to Q for L5, L7, L8
  - BEI D/P/X equal to P for L1, L5, L8
        D/P/Z equal to D for L7
  - QZS S/L/X equal to L for L1, L2, L6
        I/Q/X equal to Q for L5
        D/P/Z equal to P for L5s
        D/P/X equal to X for L8
-FILE/COMMENT
*-------------------------------------------------------------------------------
+INPUT/ACKNOWLEDGMENTS
 ESA  European Space Agency
 ESOC European Space Operations Centre
      Navigation Support Office
 IGS  International GNSS Service
-INPUT/ACKNOWLEDGMENTS
*-------------------------------------------------------------------------------
+BIAS/DESCRIPTION
 OBSERVATION_SAMPLING                          300
 BIAS_MODE                              RELATIVE
 TIME_SYSTEM                            G
 RECEIVER_CLOCK_REFERENCE_GNSS          G
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  G
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  E
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  C
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES  J
 APC MODEL                              ESA23
*SATELLITE_ANTENNA_PCC_APPLIED_TO_MW_LC YES
-BIAS/DESCRIPTION
*-------------------------------------------------------------------------------
+BIAS/SOLUTION
*BIAS SVN_ PRN STATION__ OBS1 OBS2 BIAS_START____ BIAS_END_____ UNIT __ESTIMATED_VALUE____ _STD_DEV___
 DSB  E210 E01          C1C  C5Q  2017:001:00000 2023:120:00000 ns   -.360307531411484E+00 .124448E-01
 DSB  E211 E02          C1C  C5Q  2017:001:00000 2026:078:00000 ns    0.808882941249843E+00 .124355E-01
 DSB  E208 E08          C1C  C5Q  2017:001:00000 2026:078:00000 ns    0.276361779176073E+01 .124355E-01
 DSB  E209 E09          C1C  C5Q  2017:001:00000 2026:078:00000 ns   -.140435980590626E+01 .124355E-01
 DSB  E101 E11          C1C  C5Q  2017:001:00000 2026:078:00000 ns    0.104703035440027E+02 .124359E-01
 DSB  E102 E12          C1C  C5Q  2017:001:00000 2026:078:00000 ns    0.823780778417171E+01 .124358E-01
 DSB  E202 E14          C1C  C5Q  2017:001:00000 2019:077:00018 ns   -.303123504462416E+02 .125409E-01
 DSB  E201 E18          C1C  C5Q  2017:001:00000 2019:049:00018 ns   -.152822820659627E+02 .125480E-01
 DSB  E103 E19          C1C  C5Q  2017:001:00000 2026:078:00000 ns    0.250631587619431E+01 .124361E-01
 DSB  E204 E22          C1C  C5Q  2017:001:00000 2017:342:00000 ns    0.137349003393180E+01 .126696E-01
```

Publicly available:
https://navigation-office.esa.int/products/gnss-products/ESA0OPSFIN_DCB.BIA

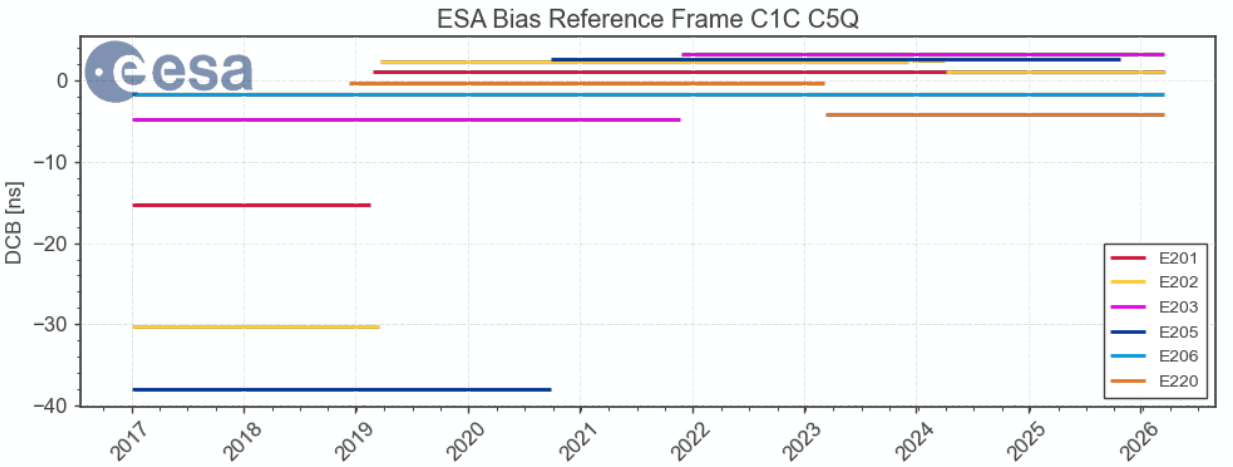
GPS P1C1 Correction using ESA BREF

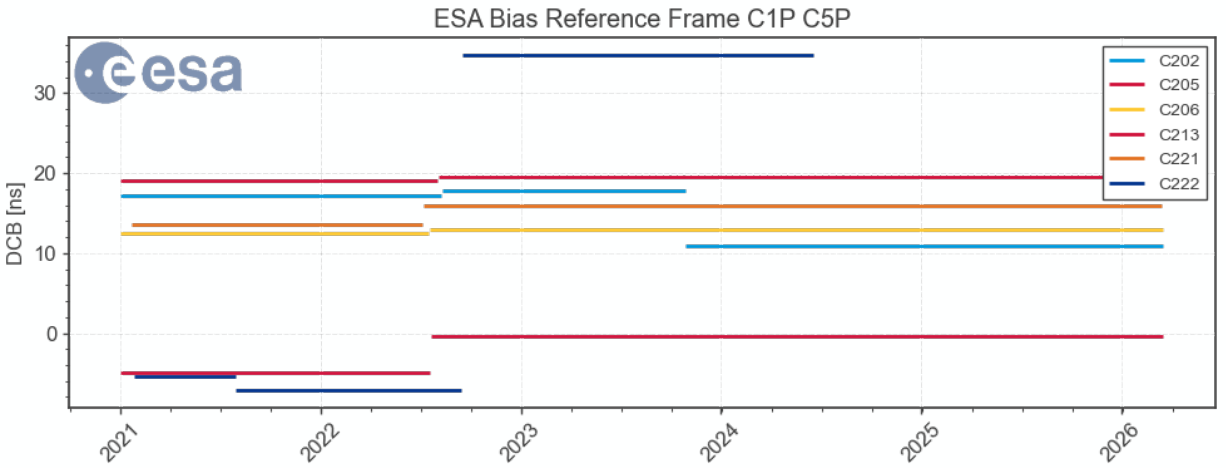
- ESA AC uses in-house data for P1C1 correction.
  - Started September 2025
  - Reduction of external dependencies
- Computed by combining BREF
  - [C1C-C2W] - [C1W-C2W] = C1C-C1W
  - Constellation zero-mean applied
- Impact on ESA AC solution in IGS0OPSFIN
  - Increasing satellite clock RMS
  - Stable satellite clock STD

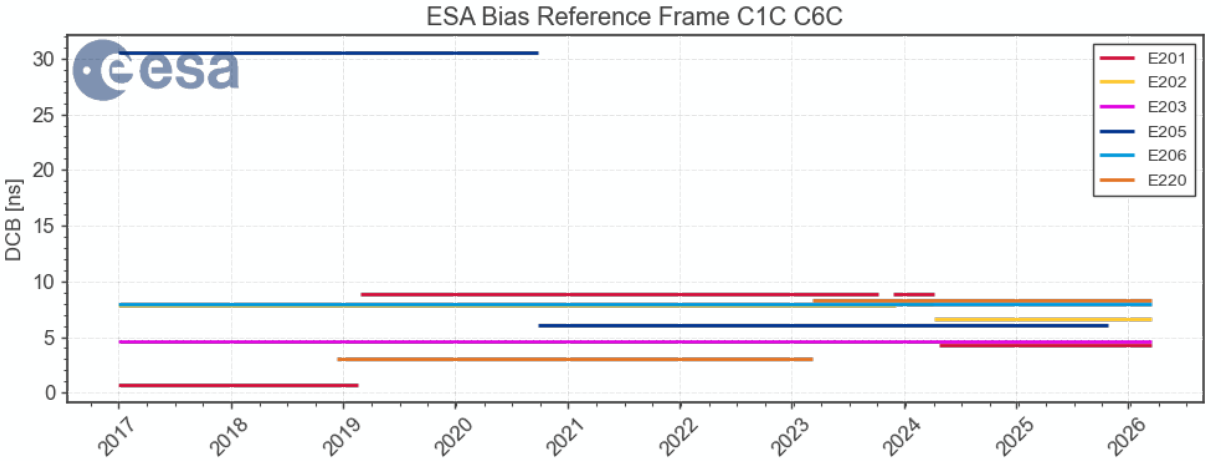


Differential Code Bias Jumps

- Numerous DCB jumps could be observed over the past decade.
- In particularly, when constraining the biases to a code Reference frame such as BREF the jumps needs to be closely monitored.



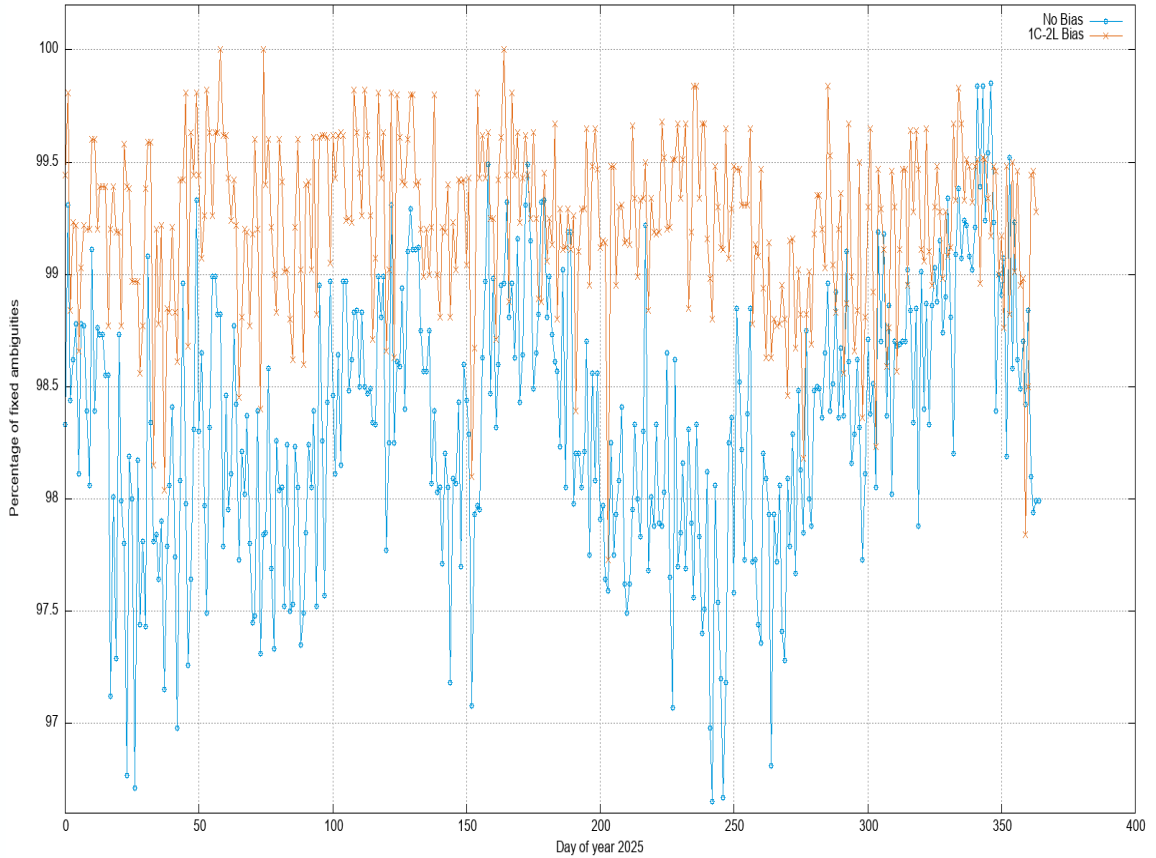




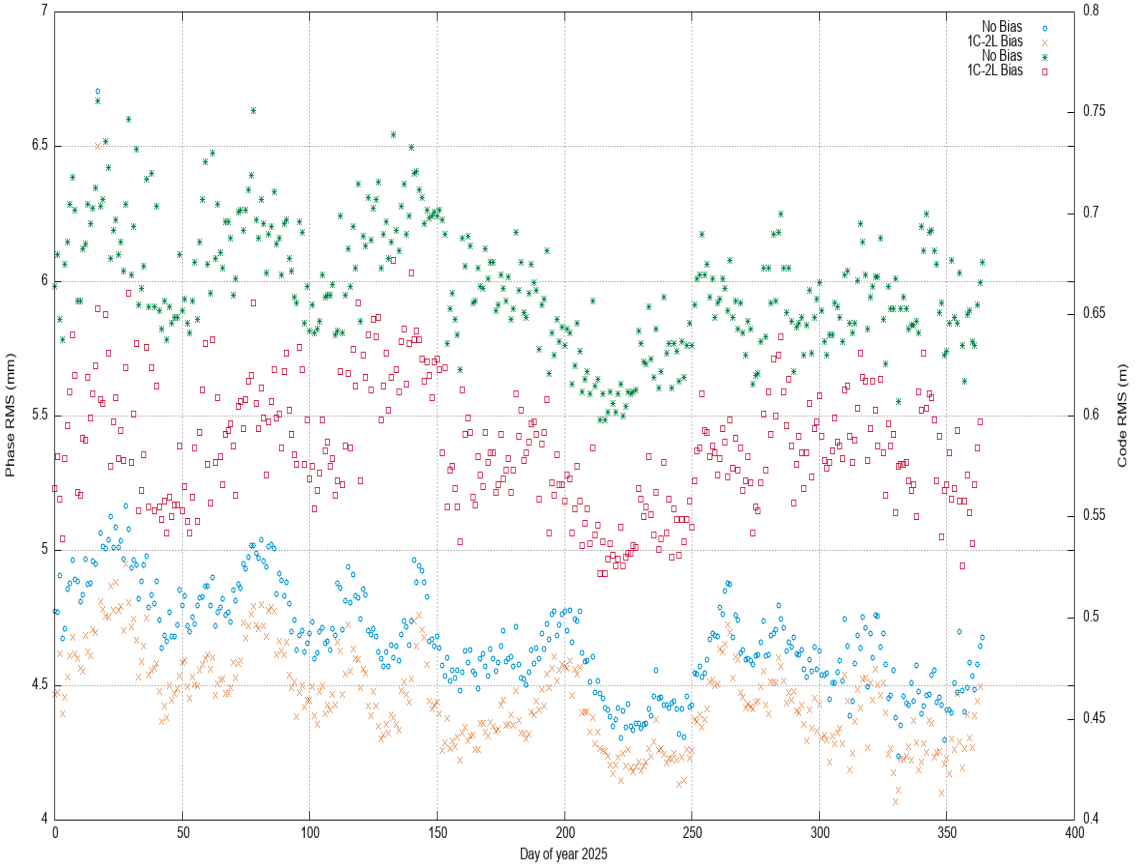
Phase Biases

- ESA generates supporting products for PPP-AR using fractional phase biases since many years.
  - For GPS phase biases make use of 1W-2W observations
  - For Galileo phase biases make use of 1C/X - 5Q/I
  - For BeiDou phase biases make use of 1P/X - 5P/X
  - and QZSS of 1L/X/S - 5Q/I/X
- The latest Sentinel satellites provide Galileo 1C-5Q and GPS 1W-2W but also GPS 1C-2L observations.
  - How can GPS 1W-2W based products (orbit, clock and phase biases) be used to process that data!?
- When correcting the code observations, it must be ensured that the phase biases remain usable.
- For many years GPS 1C has been converted to 1W like observations, which has been proven to work perfectly fine when doing PPP-AR of 1C-2W data with 1W-2W based products.
  - Logically it should be possible to produce 2L-2W biases similarly, which could make the 2L observations compatible with the 2W phase biases.
  - Disadvantage: These 1C-1W and 2L-2W biases cannot be part of a set of an internally consistent set of bias products, because the implicit assumption was that the 1W and 2W observations were bias free.
  - But it works very well!

Sentinel: Using 1C-1W and 2L-2W Biases



Percentage of integer resolved ambiguities



Code (red and green) and phase (orange and blue) RMS after ambiguity resolution.

The ESA Bias Reference Frame with Phase Biases

GNSS Processing	• Generate global GNSS solution (orbit, clock, RF) • Use ESA OSB BREF and derive phase biases
Ionosphere Model	• Estimate Global Ionosphere Model
DCB Estimation	• Generate daily estimates of all the (19) DCBs
DCB Stacking	• Long-term stacking of all the (19) DCBS
ESA DCB BREF	• Merge all (19) DCBs in one single bias-SINEX file • Add C1C-C1W code bias
ESA OSB BREF	• Convert all (19) DCBs to (23) OSBs • Full consistency of the biases for each constellation

Conclusions

- We generate and maintain a long-term differential code bias product:
  - The ESA Bias Reference Frame (BREF)
  - Available from our web-site https://navigation-office.esa.int/products/
- We generate phase biases for all GNSS systems:
  - GPS, Galileo, BeiDou and QZSS (GLONASS excluded for obvious reasons (FDMA))
  - Not (yet) publicly available
- Our code and phase bias products are state-of-the-art.
  - Using our phase biases requires special biases when used with other code signals.
    - For C1C one would need the well know C1C-C1W biases.
    - For C2L one would need the C2L-C2W biases.
- Our ESA BREF is currently containing only DSBs.
  - We will generate and maintain an OSB version of it (soon).
  - We will generate phase biases consistent with our ESA OSB BREF.

Thank you for your Attention

ESA-ESOC Navigation Support Office team
based in Darmstadt, Germany

https://navigation-office.esa.int

navigation-office@esa.int

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P1 08	GSSC: GNSS Science Support Centre – ESA's IGS Global Data Centre
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P2 17	An Update on Genesis Mission Status