

BDS/QZSS Satellite Antenna Calibration Campaign

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Inclusion of BDS-3 and QZSS in operational IGS products to cover all available constellations

Consistent set of satellite antenna phase center offsets and patterns **compatible** with the **IGS20** reference frame

- BDS-3 MEO and IGSO
- QZSS (PCOs only)

Current Status: BeiDou-3



Manufacturer calibrations provided by Test and Assessment Research Center of China Satellite Navigation Office:

- Frequency-specific phase center offsets: B1, B2, B3
 - Included in igs20.atx for BeiDou-3
 - Recent BeiDou-3 satellites missing

Estimation:

- Phase Center offsets:
 - Zajdel et al. (2022), Huang et al. (2023), esa23.atx by ESA/ESOC
- Phase patterns:
 - Estimation of block-specific phase patterns by ESA/ESOC for B1I/B3I

Zajdel et al. (2022). On the potential contribution of BeiDou-3 to the realization of the terrestrial reference frame scale. *GPS Sol*, 26(4). <https://doi.org/10.1007/s10291-022-01298-0>

Huang et al. (2023). Estimation of antenna phase center offsets for BDS-3 satellites with the metadata and receiver antenna calibrations. *J Geod*, 97(6). <https://doi.org/10.1007/s00190-023-01757-7>

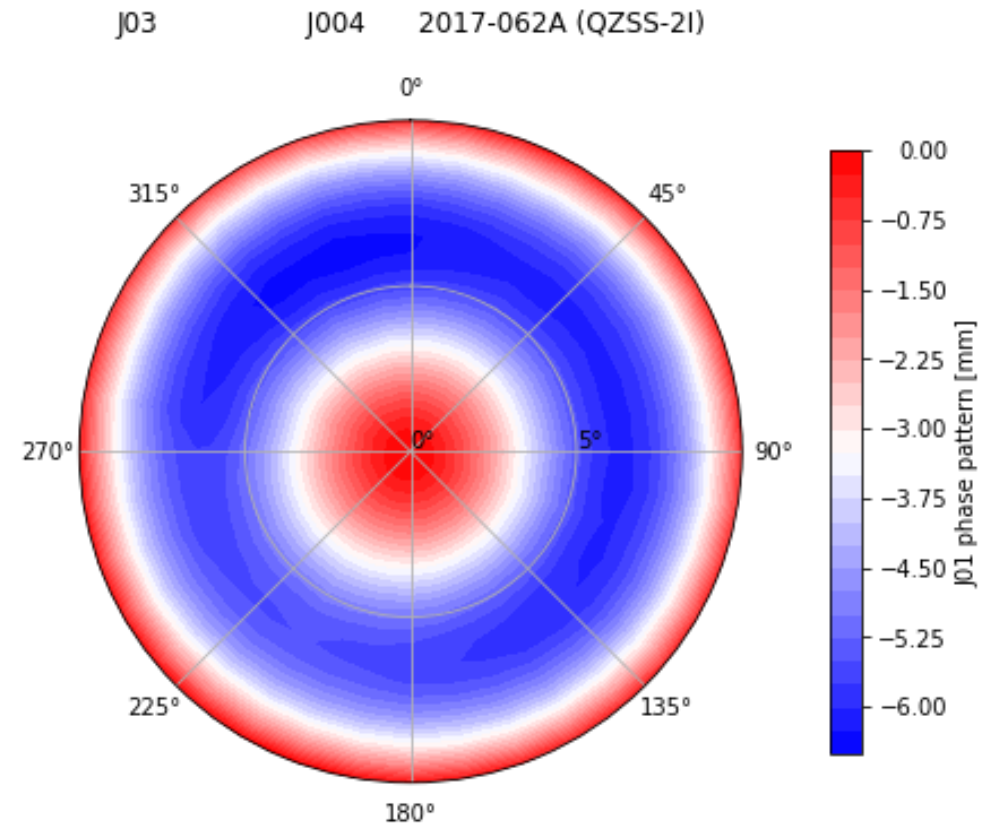
<http://navigation-office.esa.int/products/metadata/esa23.atx>

<http://navigation-office.esa.int/products/metadata/bds3meo.atx>

Current Status: QZSS

Manufacturer calibrations provided by Cabinet Office, Government of Japan:

- Frequency-specific: L1, L2, L5, L6
- Phase center offsets
- Phase patterns:
 - $\Delta A_z = 10^\circ$
 - $\theta_{\max} = 10^\circ$, $\Delta\theta = 0.5^\circ$



Cabinet Office: *QZSS Satellite Information*. Government of Japan, National Space Policy Secretariat. <https://qzss.go.jp/en/technical/qzssinfo/index.html>

BDS/QZSS Satellite Antenna Calibration Campaign



Initiated by Reference Frame Committee with support from MGEX Pilot Project and Antenna Committee

- Step 1: Estimation of BDS-3 **phase patterns** for B1C/B2a
- Step 2: Estimation of BDS-3 and QZSS **phase center offsets**
- Step 3: Evaluation of **impact on IGS OPS products**

Phase Pattern Estimation



Estimation of nadir-dependent phase pattern with 1° resolution

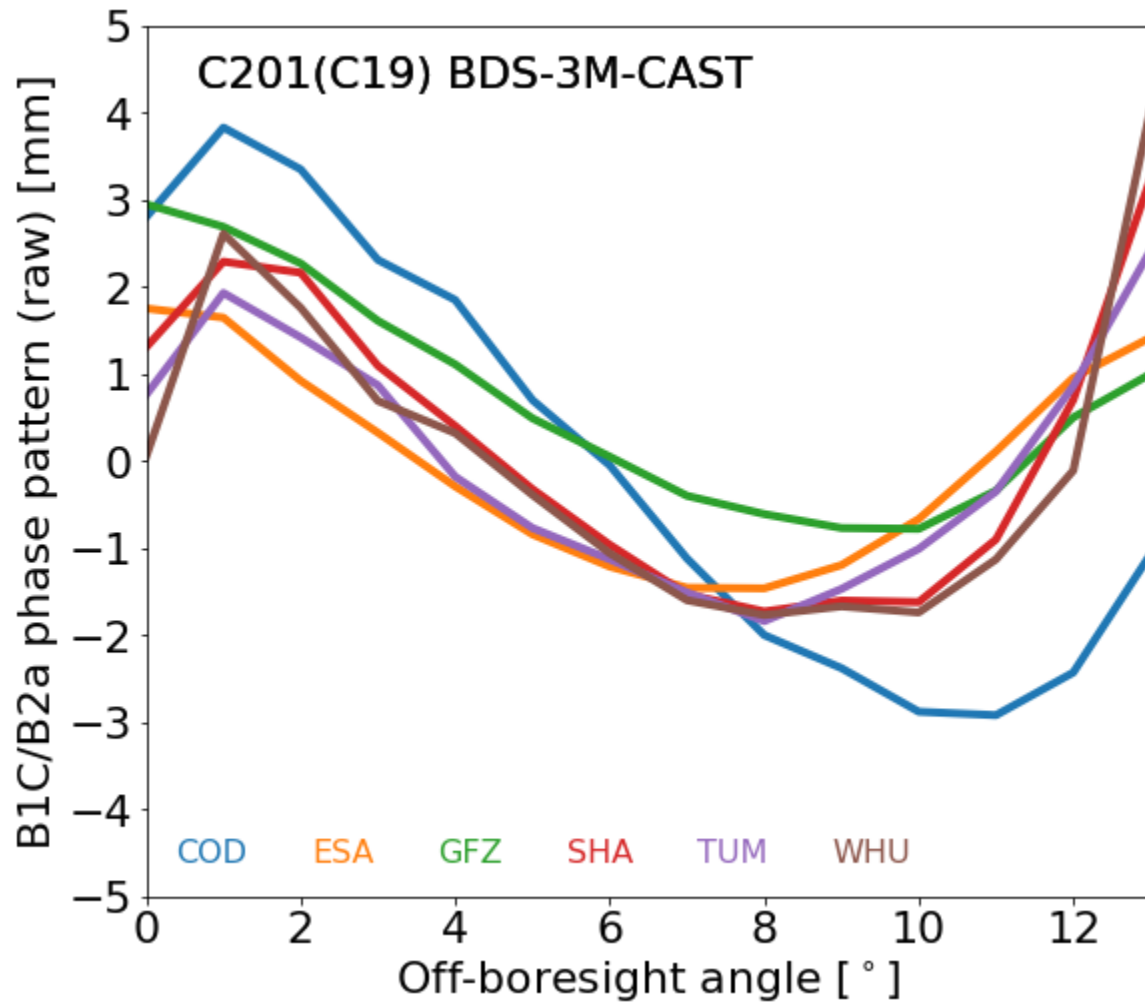
- Ionosphere-free linear combination of B1C and B2a observations
- Satellite-specific, up to 13° for MEOs, up to 9° for IGSOs
- 1 year of data
- Comparison and combination on solution level

Analysis Center	MEO	IGSO
CODE, Switzerland	x	x
ESA/ESOC, Germany	x	
GFZ Potsdam, Germany	x	
Shanghai Observatory, China	x	x
Technische Universität München, Germany	x	x
Wuhan University, China	x	x

BDS-3 block types:

- BDS-3M-CAST
- BDS-3M-SECM-A
- BDS-3M-SECM-B
- BDS-3I

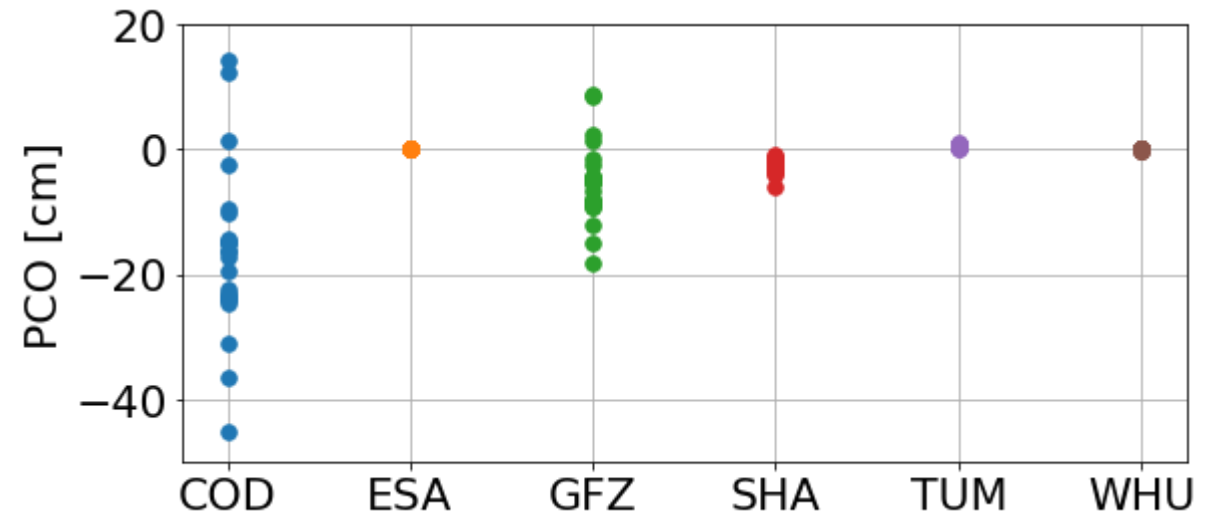
Estimated Raw Phase Patterns



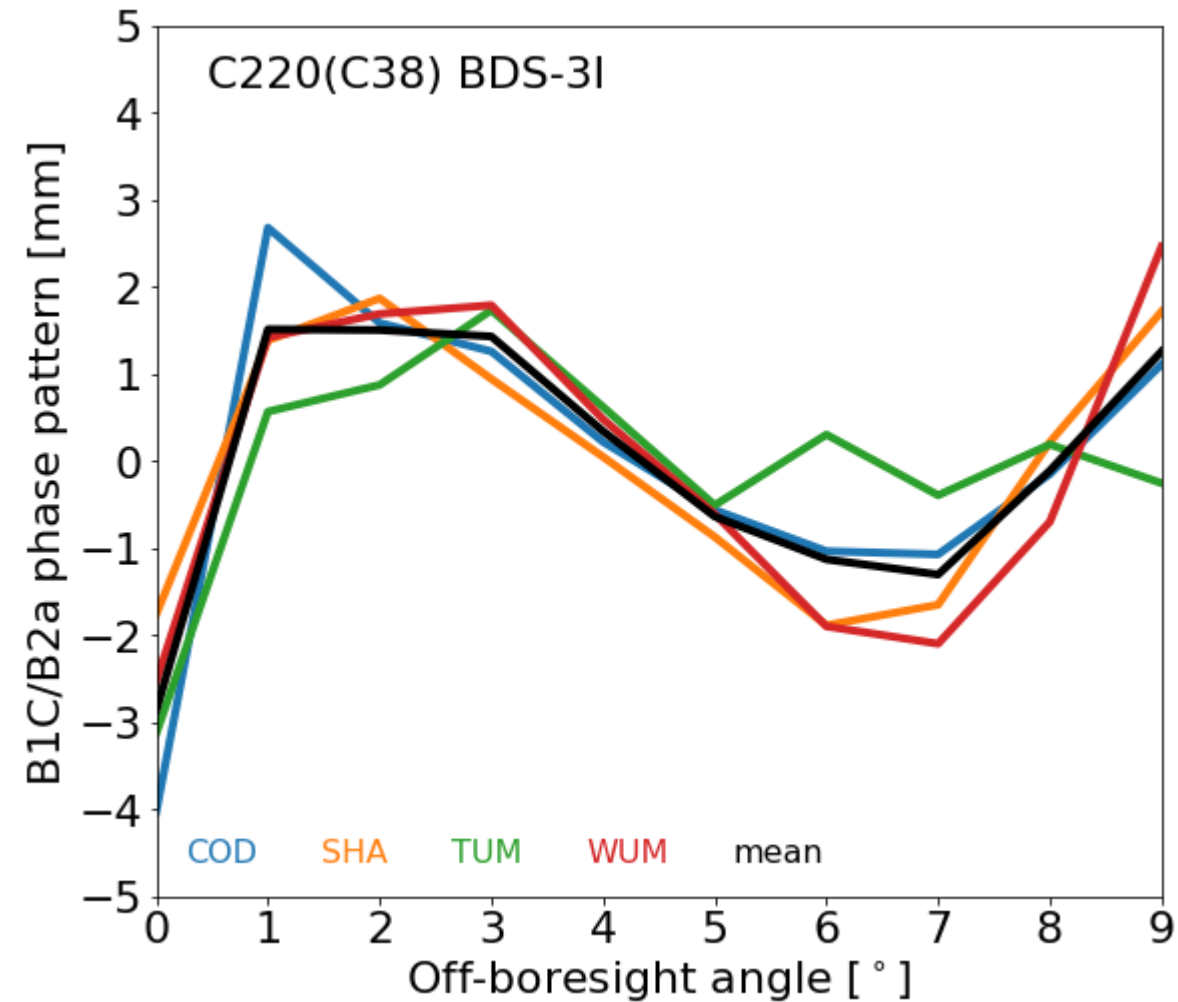
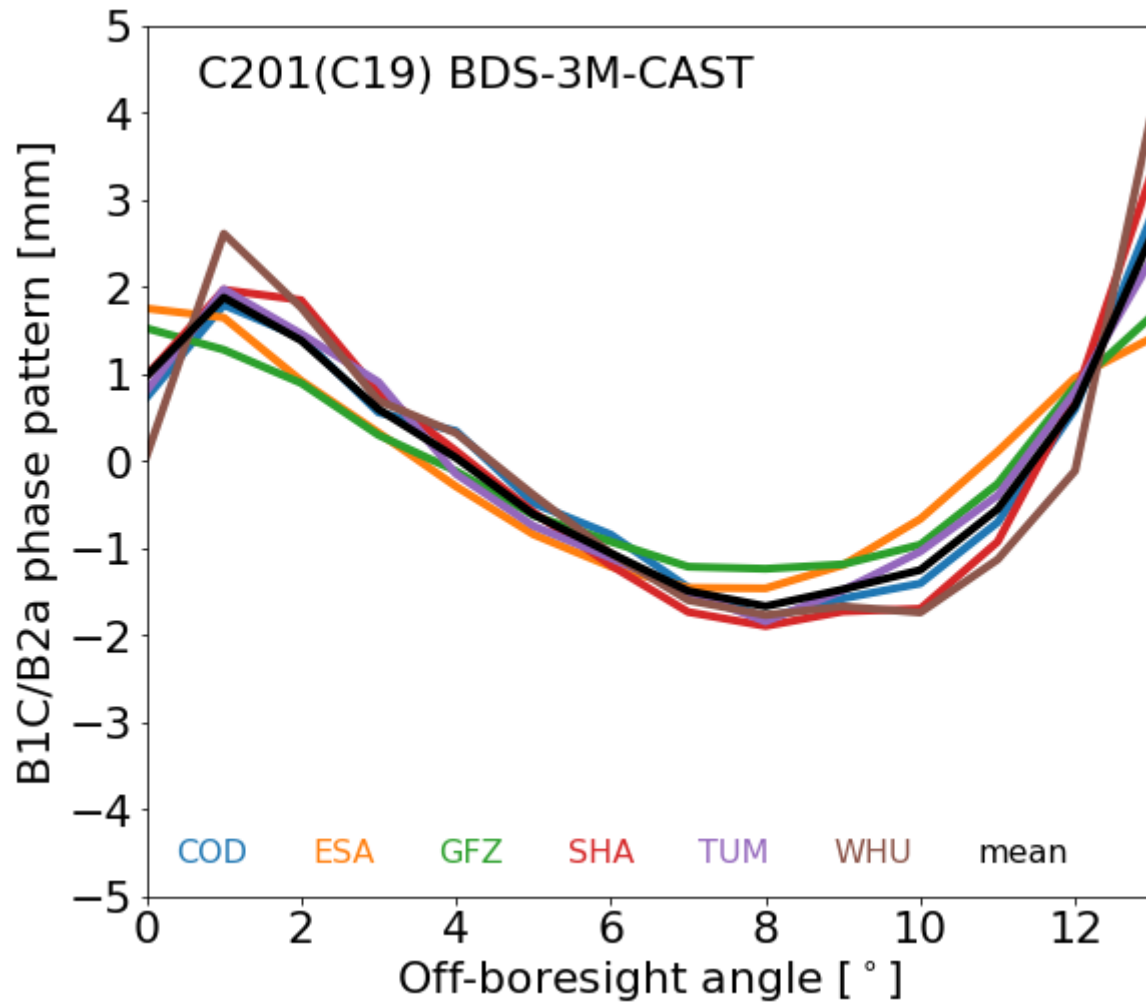
Removal of PCO component

$$\Delta\varphi = (1 - \cos\theta) \cdot \Delta z + b$$

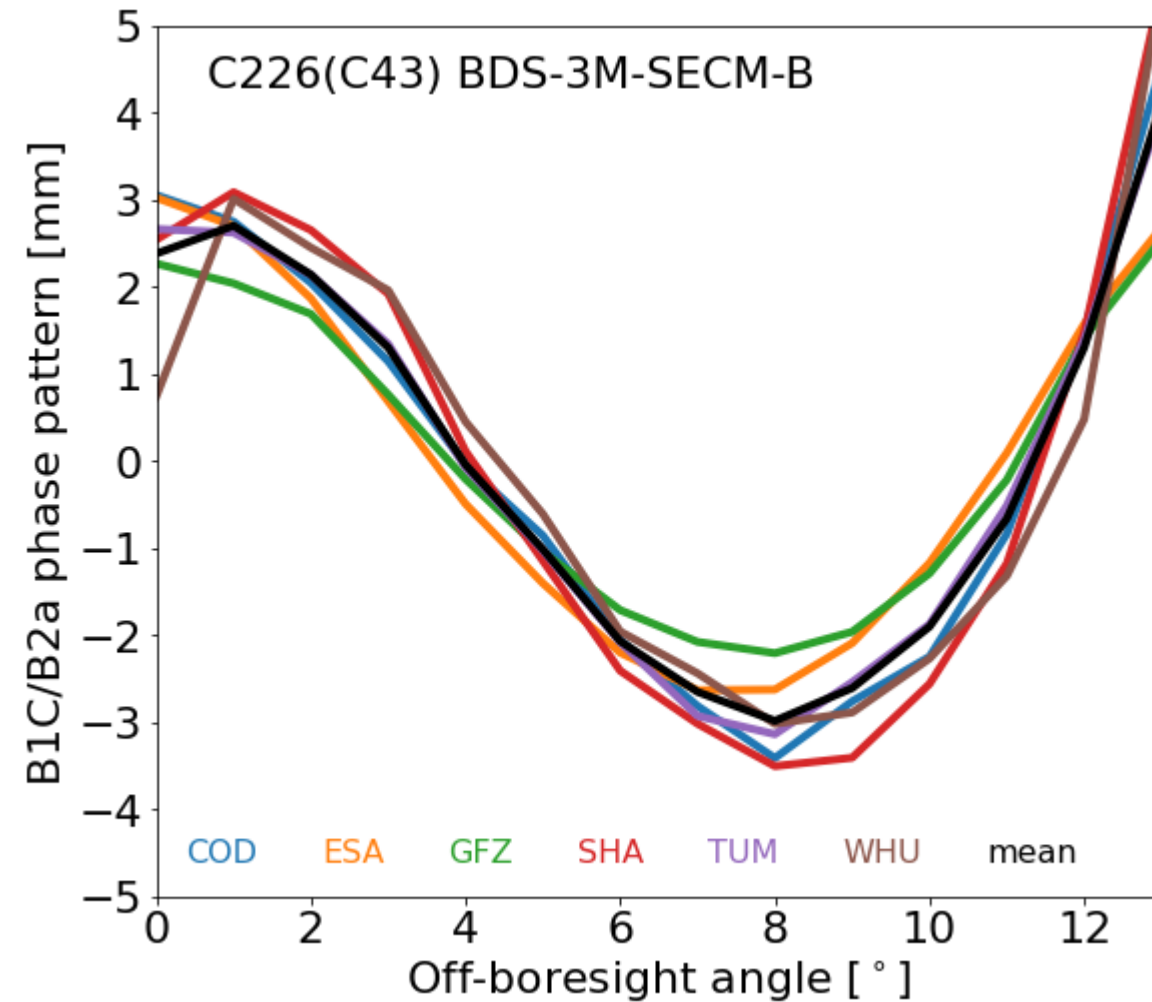
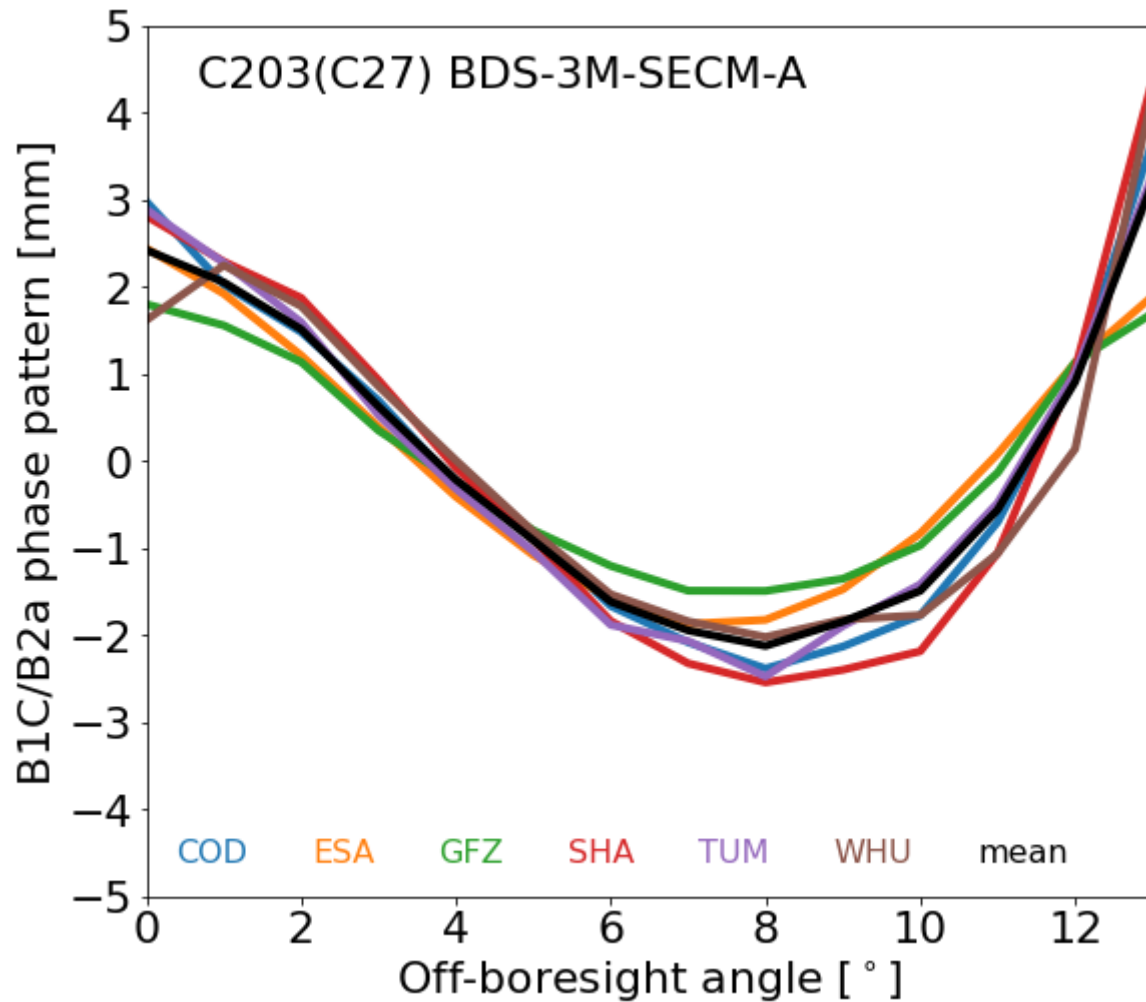
$$\sum_{k=0}^{\theta_{\max}} \varphi_k^2 \stackrel{!}{=} \min$$



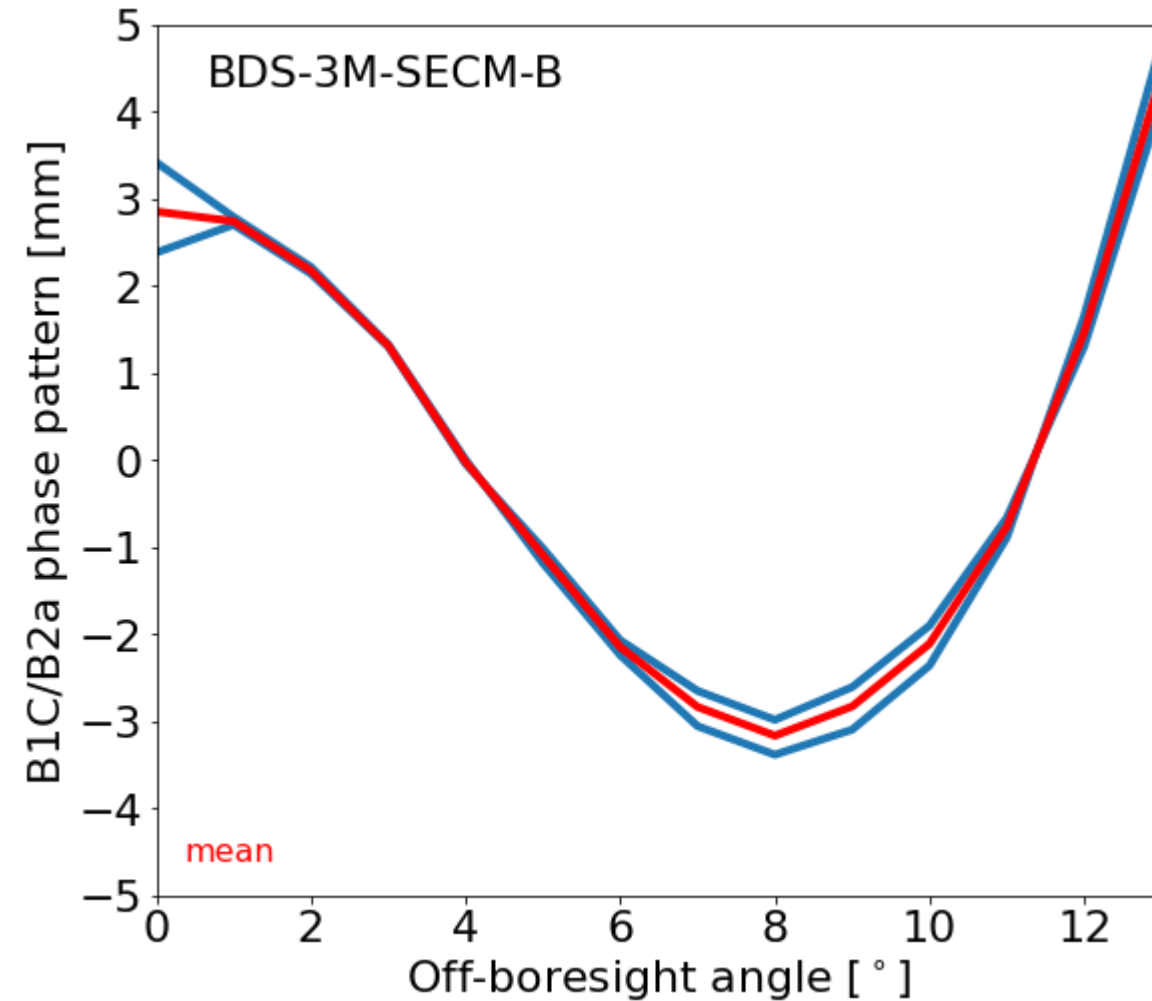
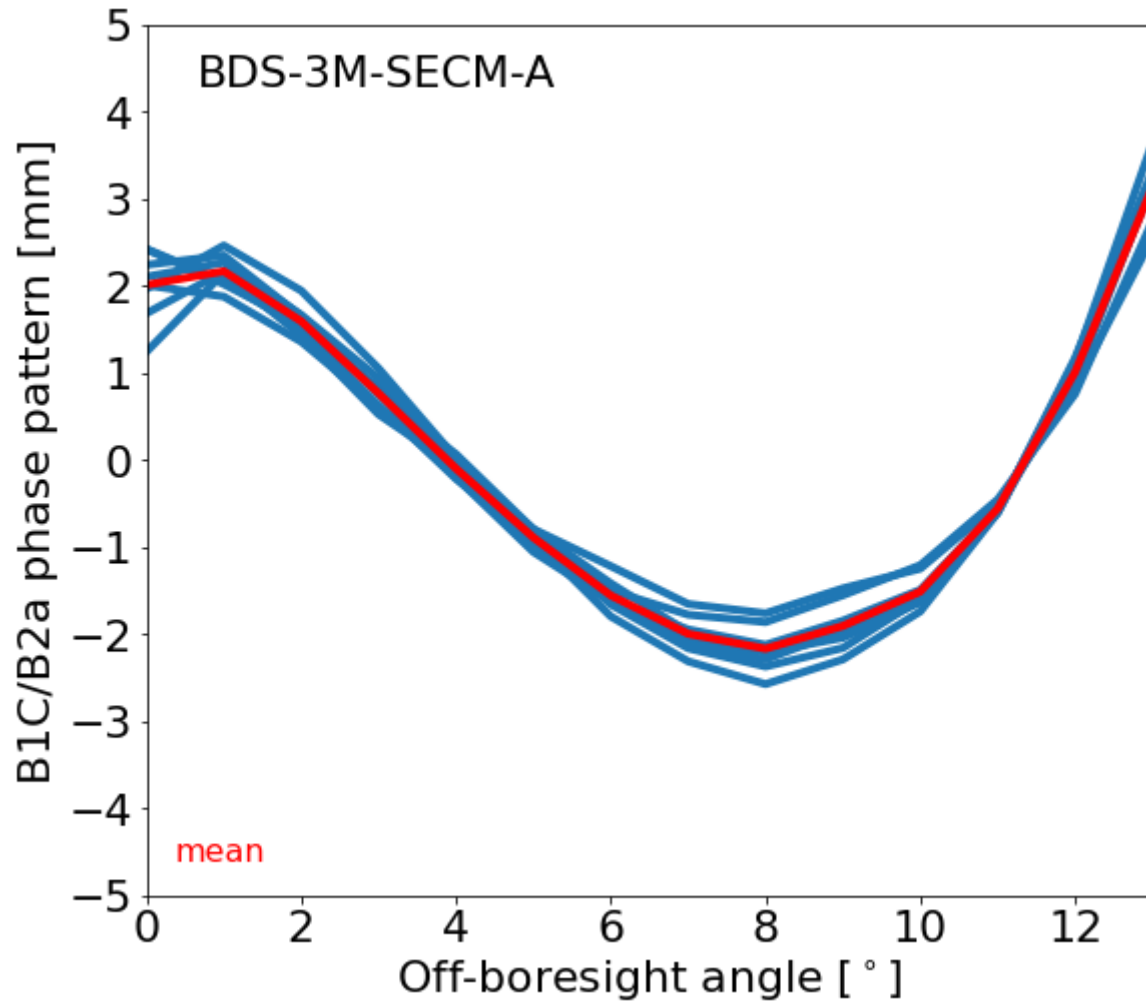
Satellite-specific Phase Patterns (1)



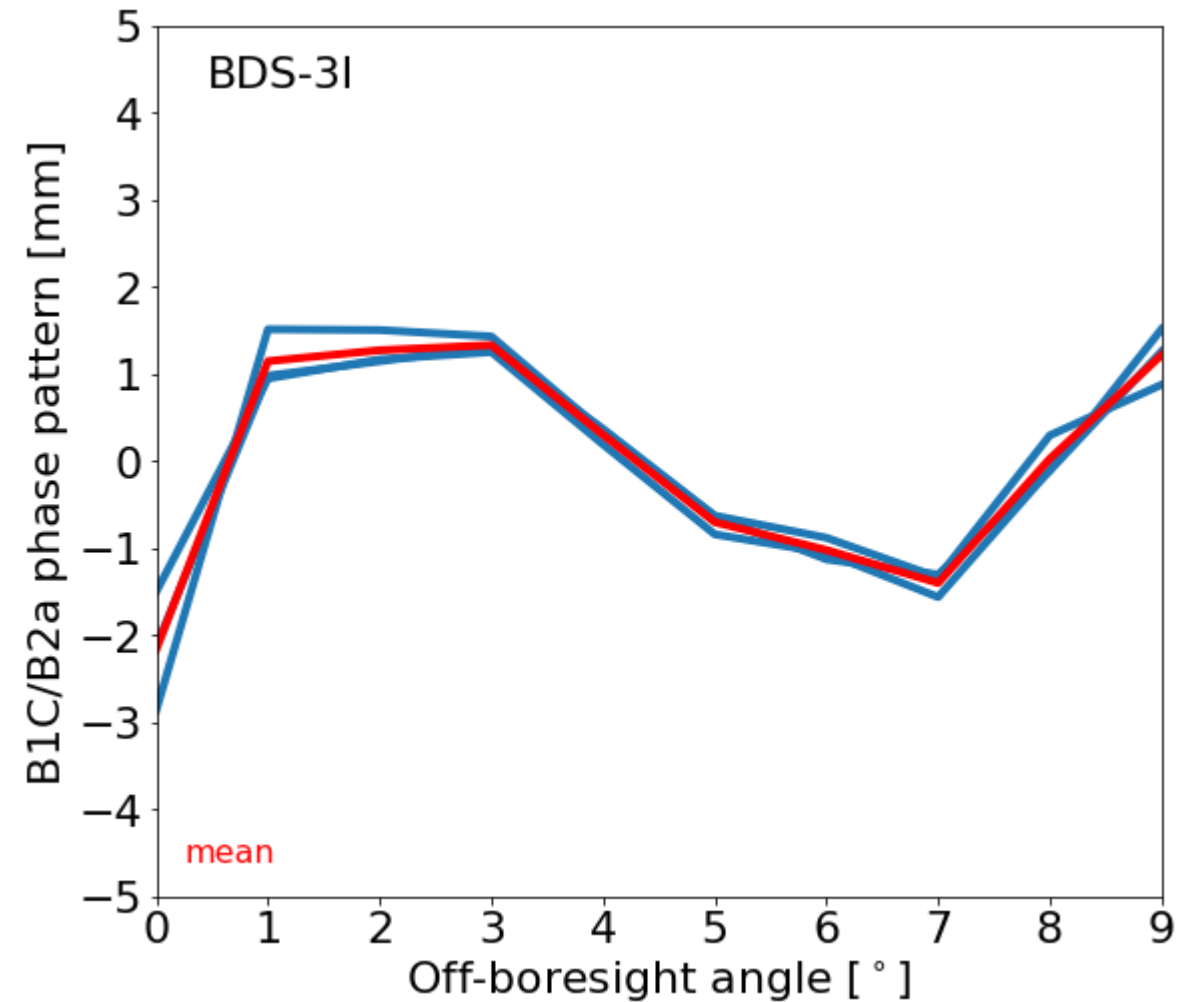
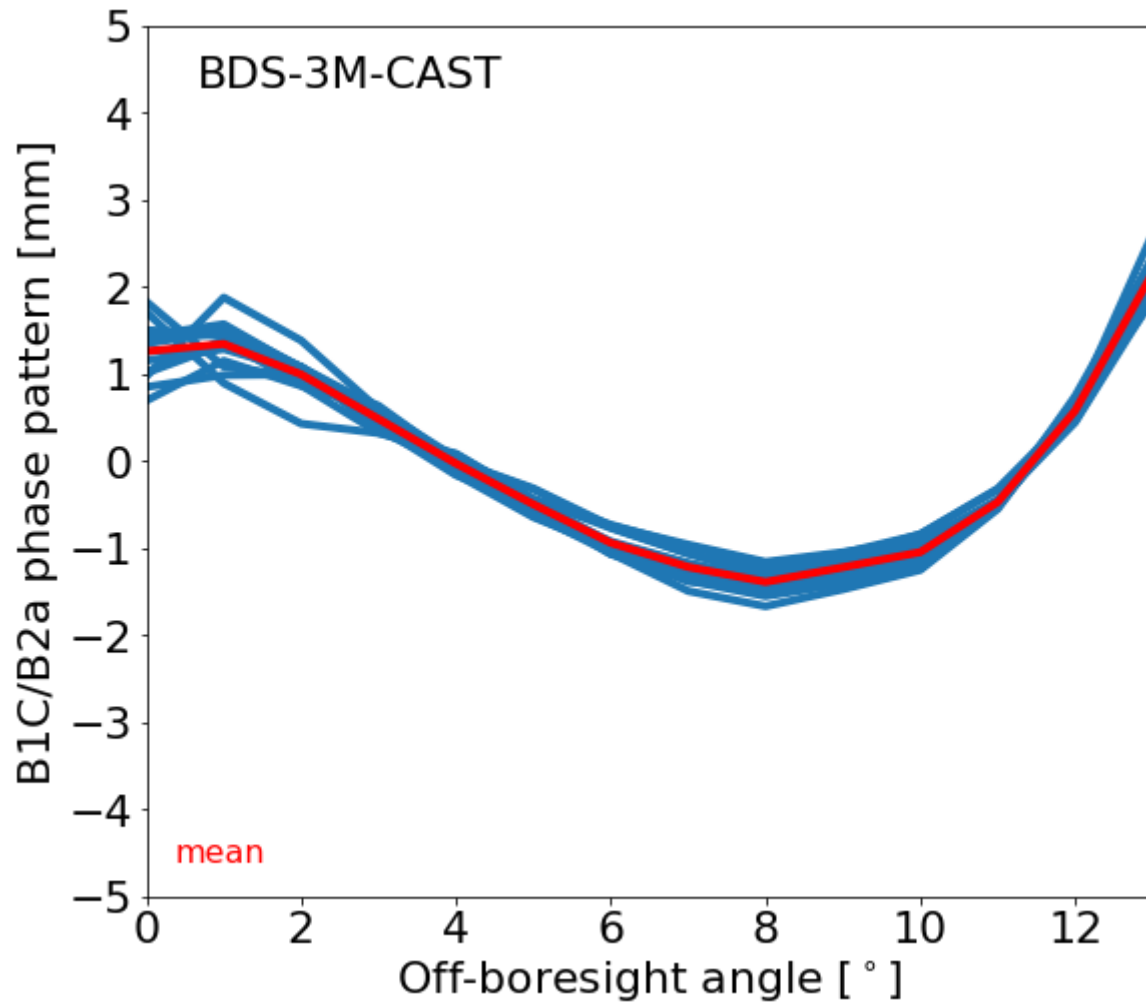
Satellite-specific Phase Patterns (2)



Block-specific Phase Patterns (1)



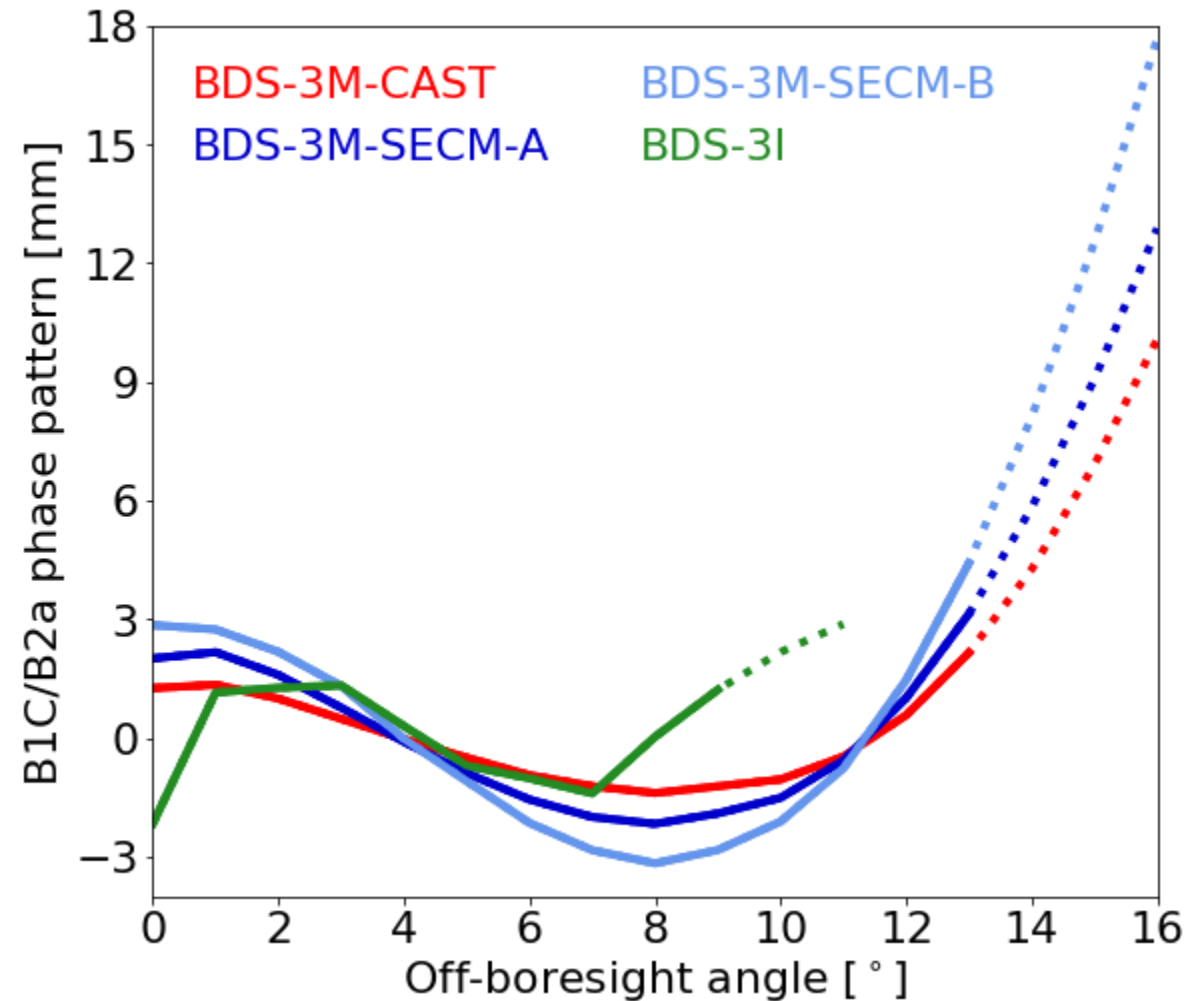
Block-specific Phase Patterns (2)



Phase Pattern Extrapolation



- Low-elevation observations of terrestrial receivers require phase patterns at 13.2°
- Support of LEO data processing
- Quadratic extrapolation for nadir angles:
 - $11\text{-}13^\circ$ up to 16° for MEO satellites
 - $7\text{-}9^\circ$ up to 11° for IGSO satellites



Phase patterns:

- IGSO/MEO
 - B1C and B2a: ionosphere-free
 - Other frequencies set to zero
- GEO
 - Set to zero

Phase center offsets

- Manufacturer values from igs20_2315.atx

BEIDOU-3M-CAST MIXED	C19 CAST/IGS	C201	2017-069A 07-JUN-24	START OF ANTENNA TYPE / SERIAL NO METH / BY / # / DATE
0.0				DAZI
0.0 15.0 1.0				ZEN1 / ZEN2 / DZEN
6				# OF FREQUENCIES
2017 11 05 00 00 00.0000000				VALID FROM
2018 06 13 00 00 00.0000000				VALID UNTIL
C01				START OF FREQUENCY
-208.10 -2.70 1487.20				NORTH / EAST / UP
NOAZI 1.26 1.35 0.99 0.48 -0.03 -0.50				-0.94 -1.22 -1.39
C01				END OF FREQUENCY
C02				START OF FREQUENCY
-208.10 -2.70 1487.20				NORTH / EAST / UP
NOAZI 0.00 0.00 0.00 0.00 0.00 0.00				0.00 0.00 0.00
C02				END OF FREQUENCY
C05				START OF FREQUENCY
-212.60 -0.90 1096.50				NORTH / EAST / UP
NOAZI 1.26 1.35 0.99 0.48 -0.03 -0.50				-0.94 -1.22 -1.39
C05				END OF FREQUENCY
C06				START OF FREQUENCY
-209.40 1.00 1212.80				NORTH / EAST / UP
NOAZI 0.00 0.00 0.00 0.00 0.00 0.00				0.00 0.00 0.00
C06				END OF FREQUENCY
C07				START OF FREQUENCY
-212.60 -0.90 1096.50				NORTH / EAST / UP
NOAZI 0.00 0.00 0.00 0.00 0.00 0.00				0.00 0.00 0.00
C07				END OF FREQUENCY
C08				START OF FREQUENCY
-212.60 -0.90 1096.50				NORTH / EAST / UP
NOAZI 0.00 0.00 0.00 0.00 0.00 0.00				0.00 0.00 0.00
C08				END OF FREQUENCY
				END OF ANTENNA

Phase Center Offset Estimation



- Consistent with IGS20 reference frame
- 2.5 – 3 years period (July 2021 – June 2024)
- Signal selection
 - BeiDou-3: B1C/B2a
 - QZSS: L1C/L5 (future QZSS satellites will not transmit L1C/A and L2C)
- SINEX files
 - Station coordinates, ERPs, PCOs
- Submission Deadline: November 1, 2024

Evaluation of Impact on Operational IGS Products



- Evaluation to be carried out on a **case-by-case basis**, i.e., every time an AC wishes to add BDS-3 and/or QZSS in their operational products
- **Parallel “OPS+” solution** series to be generated, preferably with detailed levels of extension, e.g., +BDS MEOs, +BDS MEOs/IGSOs, +BDS MEOs/IGSOs + QZSS, ...
- Evaluation of **impact on SINEX products** by Reference Frame Committee
- Evaluation of **impact on (GPS, GLO, GAL) orbit/clock products** by ACC
- **Final decision** on incorporation of new GNSSs into OPS products of individual ACs

Summary



- Block-specific B1C/B2a phase patterns based on results of 6 (4) analysis centers for BDS-3 MEO and IGSO satellites
- Slightly better consistency of
 - CAST compared to SECM
 - MEO satellites compared to IGSO satellites
- ANTEX file as basis for estimation of BDS-3 phase center offsets
- Next steps
 - BDS-3 and QZSS phase center offset estimation, validation, combination (11/2024)
 - Consolidated set of BDS-3 and QZSS phase patterns and phase center offsets (12/2024)
 - Evaluation of impact on operational IGS products (at ACs' request)
 - Inclusion of BDS-3 and QZSS in operational IGS products