Multi-GNSS differential code biases (DCBs) estimation within MGEX

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Motivation

- Differential Code Biases (DCBs) are defined as

  the biases between two code observations at the same/different frequencies

- GNSS DCBs are needed for

  code based positioning, ionospheric TEC extraction, etc.

- Most current DCB products limit to legacy GPS and GLONASS signals

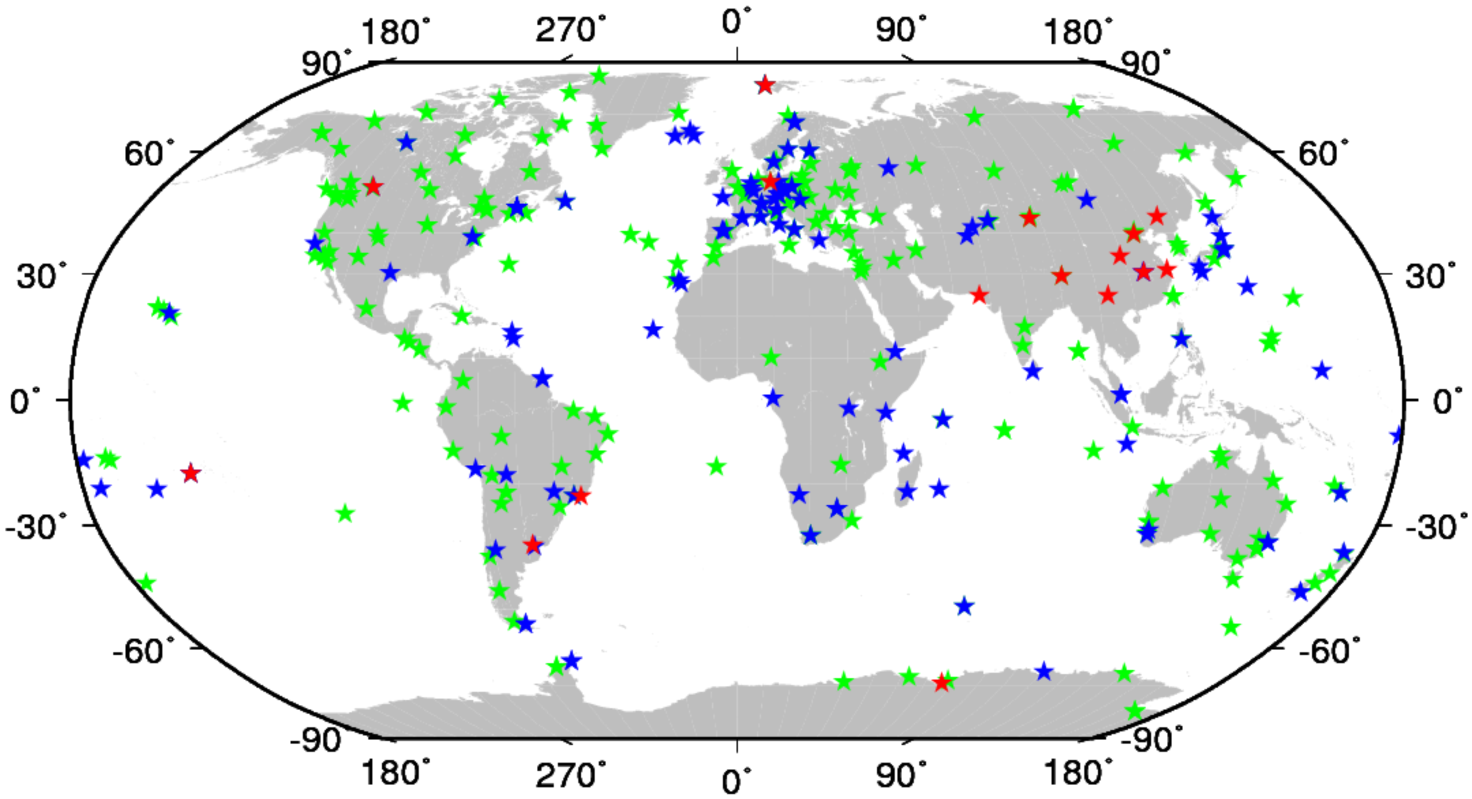
  IGS Ionospheric Analysis Centers (IIACs, including CODE, UPC, ESA, JPL)

- Multi-GNSS DCB products are needed with the new emerging constellations (BDS and Galileo) and new signals

- Multi-GNSS Experiment (MGEX) network offers an independent basis for Multi-GNSS DCB determination
- German Aerospace Center (DLR) proposes a simplified method for DCB estimation using Global Ionosphere Maps (GIMs)
- Considering the multiplicity of MGEX DCB products, IGGDCB method is extended for Multi-GNSS DCB estimation

Tracking Network

MGEX network shows a global coverage (~140 stations), supporting to track GPS, GLONASS, BDS, Galileo and QZSS signals



Green: IGS, GPS+GLO, ~400 sites
Blue: MGEX, GPS+GLO+BDS+GAL, ~140 sites
Red: iGMAS, GPS+GLO+BDS+GAL, ~15 sites

IGS DCB Products

- GPS + GLONASS
- Code observations: C1, P1, P2 (P1-C1 and P1-P2)
- Global ionospheric TEC modeling + DCB estimation
- Zero-constellation-mean constraint for satellite and receiver DCB separation
- DCB products: CODE (monthly interval, Bernese format) [1]
  IIACs (daily interval, IONEX format) [2]

MGEX DCB Products

- GPS + GLONASS + BDS + Galileo
- All tracked signals (no QZSS)
- Processing scheme: DLR (DCB determination using GIMs)
  IGG/CAS (station-based ionospheric modeling + DCB estimation)
- Zero-constellation-mean constraint for satellite and receiver DCB separation
- DCB products in Bias SINEX DCB Format (Version 0.01)

1. Schaer S (2012) *Overview of GNSS biases*. IGS Workshop on GNSS Biases 2012, University of Bern, Switzerland
2. Hernández-PajaresM, Juan JM, Sanz J, Orus R, Garcia-Rigo A, Feltens J, Komjathy A, Schaer S, Krankowski A (2009) *The IGS VTEC maps: a reliable source of ionospheric information since 1998*. J Geod 83(3–4):263–275

DLR – Multi-GNSS DCB determination using GIMs

- DCB from ionosphere-corrected pseudorange difference
- Take advantage of “known” ionosphere based on global ionosphere maps
    - IGS GIM product
    - Ionospheric single-layer assumption
- Zero-constellation-mean constraint

$$\underbrace{P_{S_1} - P_{S_2}}_{\text{measured}} = \left(I_{S_1} - I_{S_2}\right) + \left(B_{S_1} - B_{S_2}\right) + \overbrace{\left(M_{S_1} - M_{S_2}\right) + \left(\varepsilon_{S_1} - \varepsilon_{S_2}\right)}^{\text{averaged/ignored}}$$

$$\approx 40.28 \cdot \left(\frac{1}{f_{S_1}^2} - \frac{1}{f_{S_2}^2}\right) \cdot \underbrace{sTEC}_{\text{GIM corrected}} + \underbrace{DCB_{S_1-S_2}^{sat+rec}}_{\text{estimated}}$$

Montenbruck O, Hauschild A, Steigenberger P (2014) *Differential Code Bias Estimation using Multi-GNSS Observations and Global Ionosphere Maps*. Navigation 61(3):191–201

IGG/CAS – Multi-GNSS DCB determination with IGGDCB method

- Intra-frequency biases are directly determined from GNSS observations
- Local ionospheric model for the combined estimation of ionosphere and DCBs
  - Generalized triangular series (GTS) function
  - Ionospheric single-layer assumption

(a) measured (b) modeled with local GTS function (c) estimated

$$P_{S_1} - P_{S_2} \approx 40.28 \cdot \left(\frac{1}{f_{S_1}^2} - \frac{1}{f_{S_2}^2} \right) \cdot sTEC + DCB_{S_1-S_2}^{sat+rec}$$

- GTS function for local ionospheric modeling

$$\begin{cases} STEC(z,\varphi,h) = VTEC(\varphi,h) \cdot mf \\ VTEC(\varphi,h) = \sum_{n=0}^{n_{\max}} \sum_{m=0}^{m_{\max}} \left\{ E_{nm} (\varphi - \varphi_0)^n \cdot h^m \right\} + \sum_{k=0}^{k_{max}} \left\{ C_k \cos(k \cdot h) + S_k \sin(k \cdot h) \right\} \end{cases}$$

Wang, N, Yuan, Y, Li, Z, Montenbruck O, Tan B (2015) *Determination of differential code biases with multi-GNSS observations*. J Geod
http://dx.doi.org/10.1007/s00190-015-0867-4

MGEX DCB products overview

- Support all GPS, GLO, GAL and BDS signals (no QZSS)

- File names (long name since 10/2015)

  IGG - CAS0MGXRAP_yyyyddd0000_01D_01D_DCB.BSX.gz
  DLR - DLR0MGXFIN_yyyy0010000_nnu_07D_DCB.BSX.gz
  DLR0MGXFIN_yyyy0010000_nnu_01D_DCB.BSX.gz

- Product archives

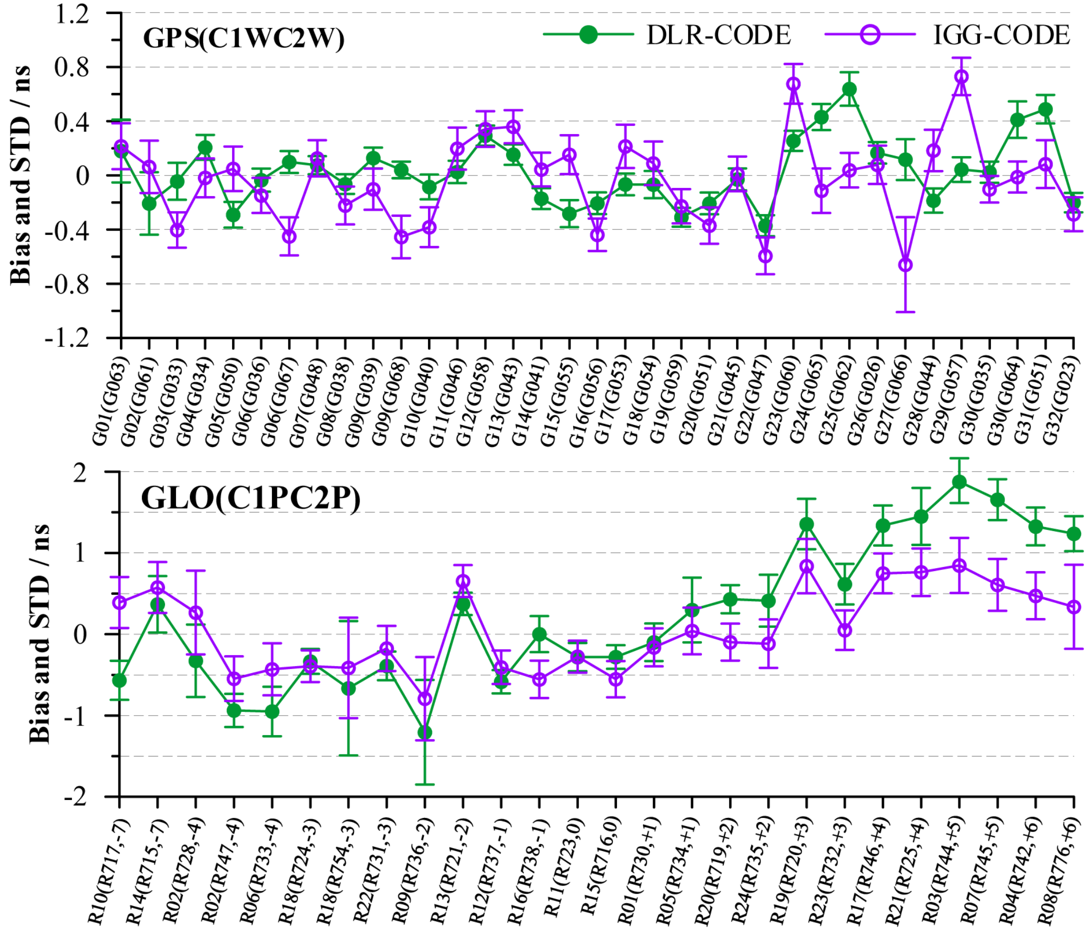
  CDDIS - ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/dcb
  IGN - ftp://igs.ign.fr/pub/igs/products/mgex/dcb

- DCB products available from 01/2013

  IGG – updated daily (daily interval)
  DLR – updated quarterly (both weekly and daily intervals)

See more:
"New Multi-GNSS Differential Code Bias (DCB) Product" [IGSMAIL -7173]

GPS and GLONASS satellite DCB results



Bias and STD of the MGEX-based C1WC2W and C1PC2P DCB estimates relative to CODE for the period 2013-2014

- RMS between IGG/DLR and CODE solutions

  (a) IGG/CAS

  GPS → C1WC2W: 0.29 ns

  GLONASS → C1PC2P: 0.56 ns

  (b) DLR

  GPS → C1WC2W: 0.24 ns

  GLO → C1PC2P: 0.84 ns

- Impact of different networks (IGS vs. MGEX) and receiver types on GNSS DCB solutions

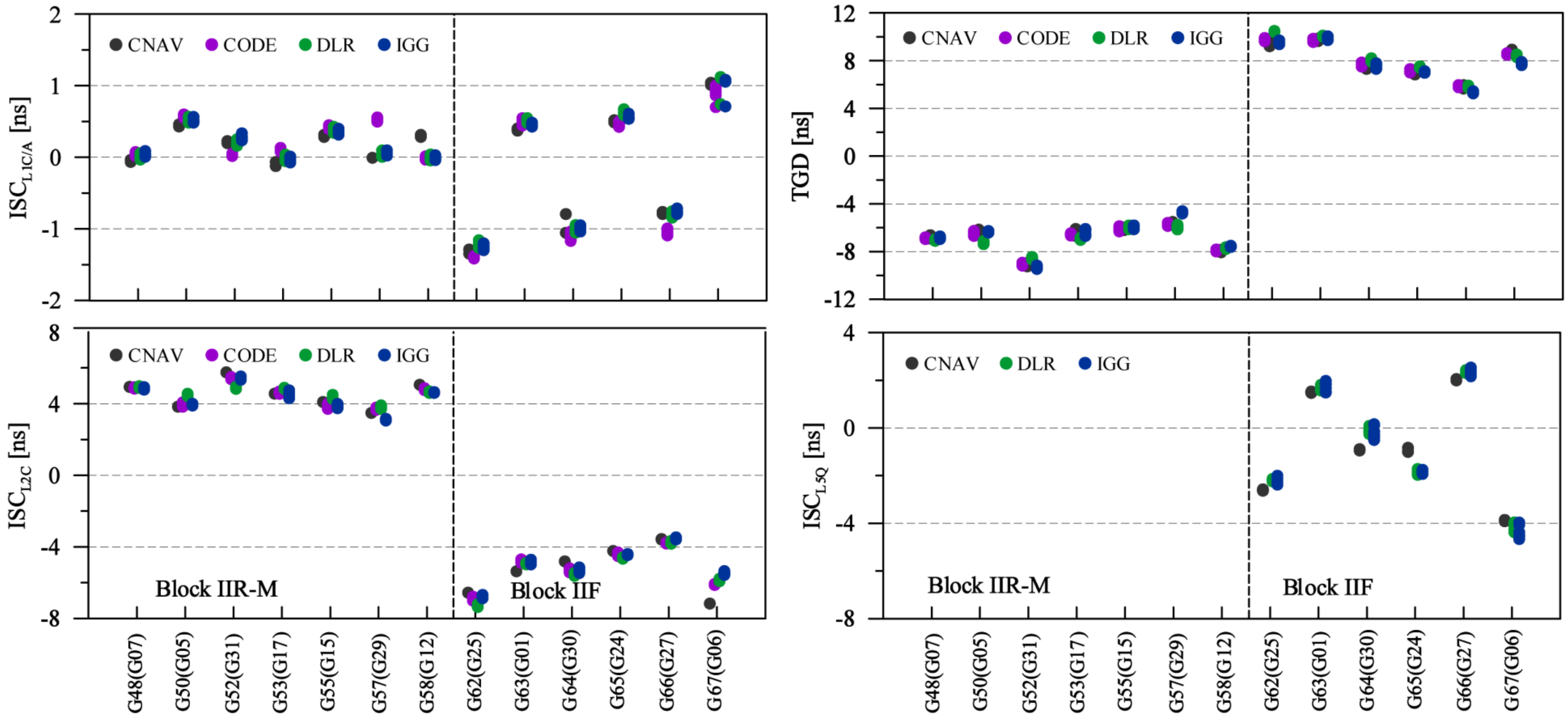
- Notable dependence on frequency channel number for both IGG and DLR GLONASS DCB solutions

Performance of GPS broadcast ISCs

- Inter-Signal Corrections (ISC) for L1C/A and new signals w.r.t L1P(Y) included in GPS Civil Navigation message (CNAV) in addition to Timing Group Delay (TGD) parameter

  ISC L1C/A, ISC L2C, ISC L5I5 and ISC L5Q5

- RMS of broadcast $ISC_{C/A}$ and IGG/DLR DCBs is about 0.2 ns, and that of TGD, ISC_{L2C} and ISC_{L5Q} is about 0.5 ns

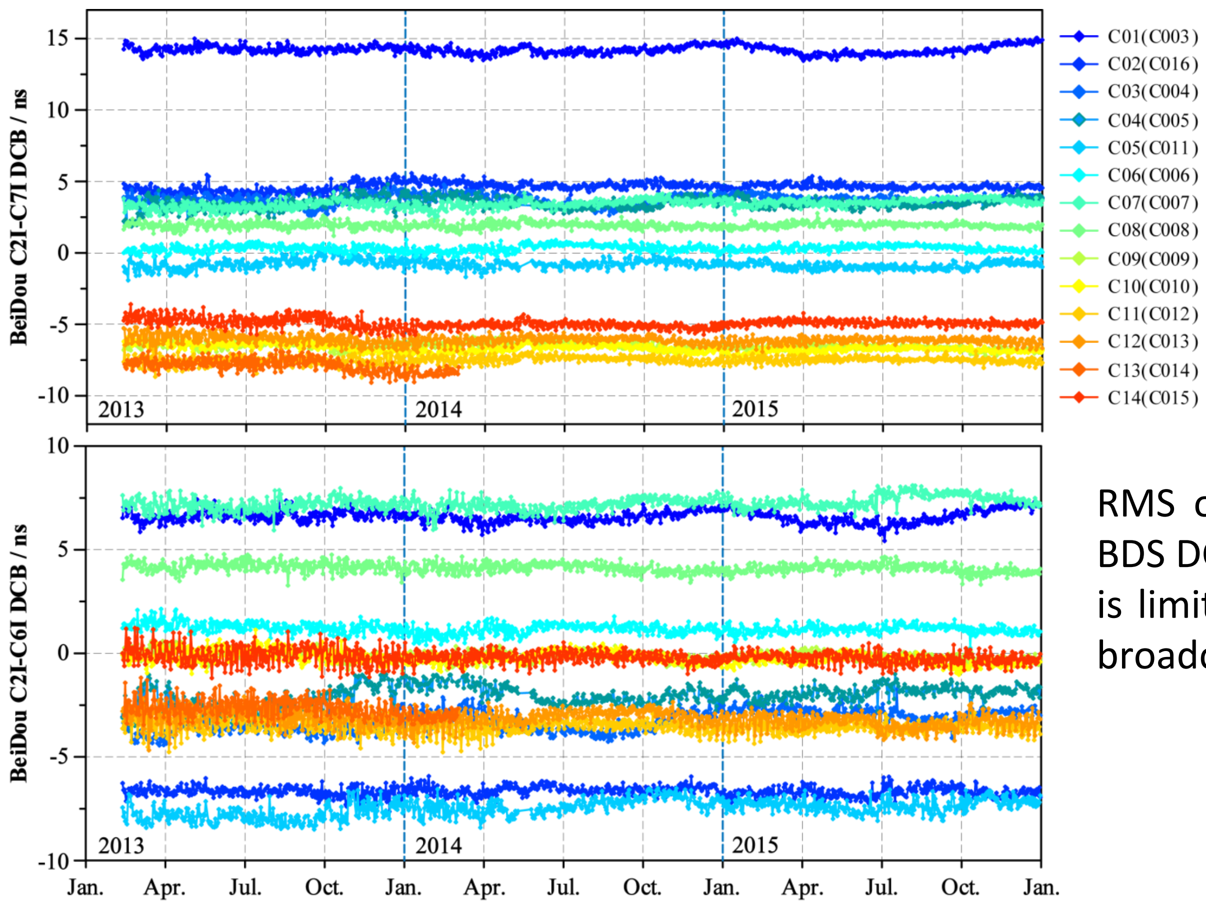


Comparison of TGD and ISC parameters from CNAV, CODE, DLR and IGG (04/2014-04/2015)

Steigenberger P, Montenbruck O, Hessel U (2015) *Performance Evaluation of the Early CNAV Navigation Message*. Navigation, 62(3): 219-228.

BDS satellite DCB results

Time series of BDS satellite C2I-C7I and C2I-C6I DCBs during the period 2013-2015

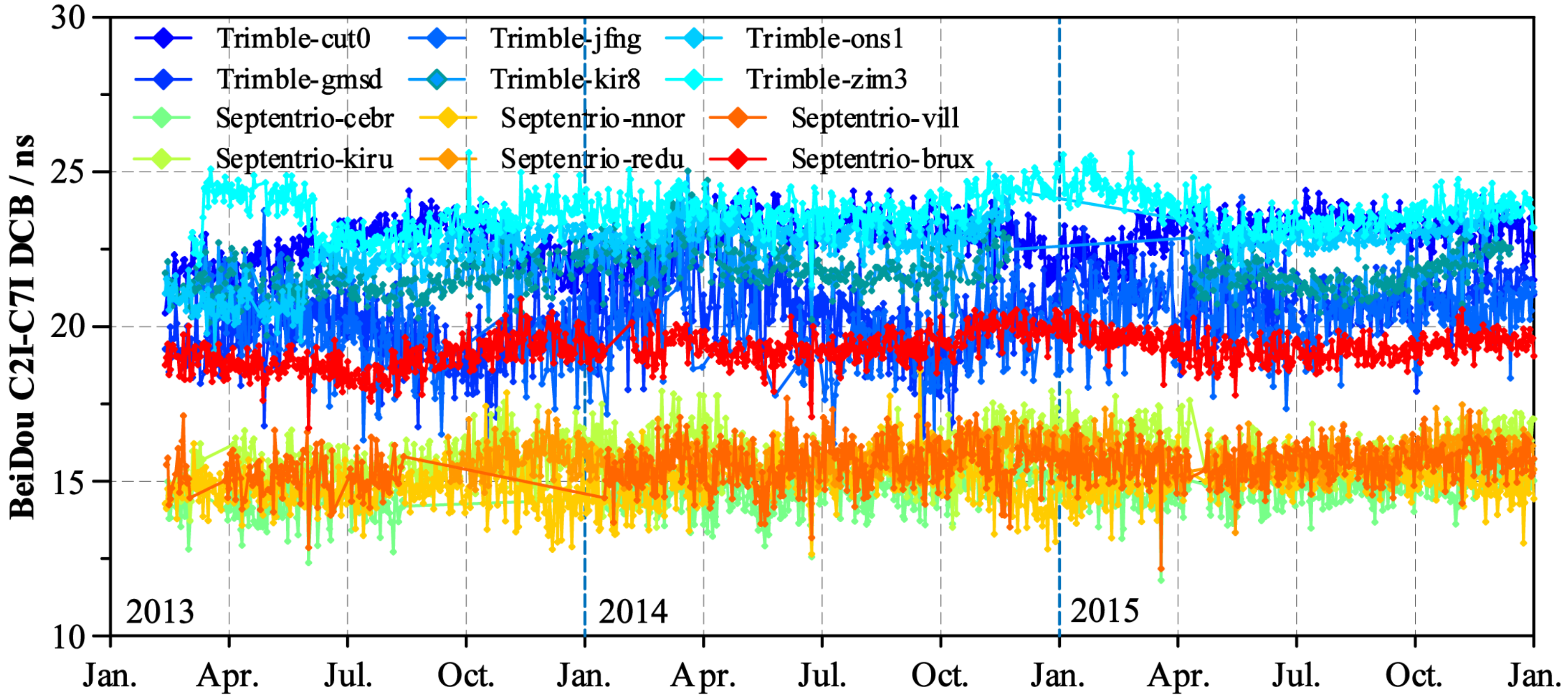


RMS of the differences between BDS DCB solutions of IGG and DLR is limited to 0.4 ns, while that of broadcast TGD is about 1.4 ns

BDS receiver DCB results

BDS receiver DCBs exhibit an dependence on receiver types

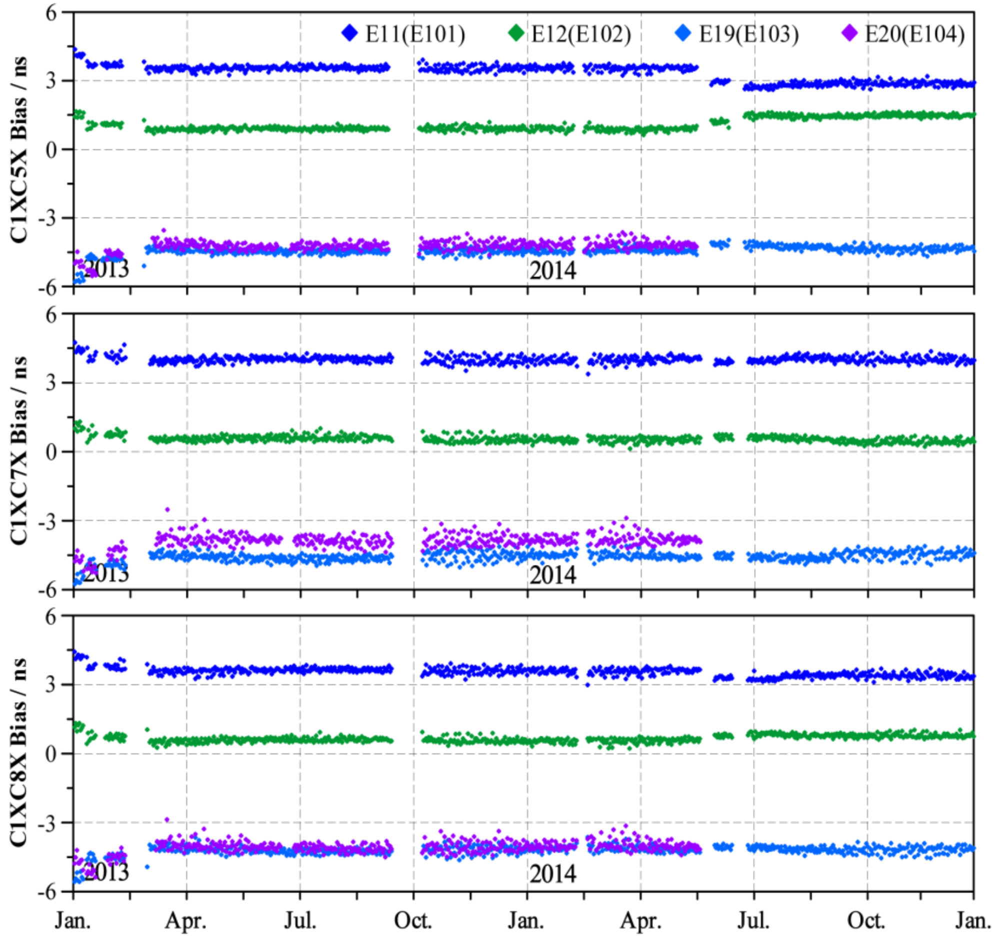
Trimble NETR9 receivers: 18.0~24.0 ns
Septentrio receivers: 13.0~19.0 ns



Time series of BeiDou C2I-C7I DCBs for the selected receivers during the period 2013–2015

Galileo satellite DCB results

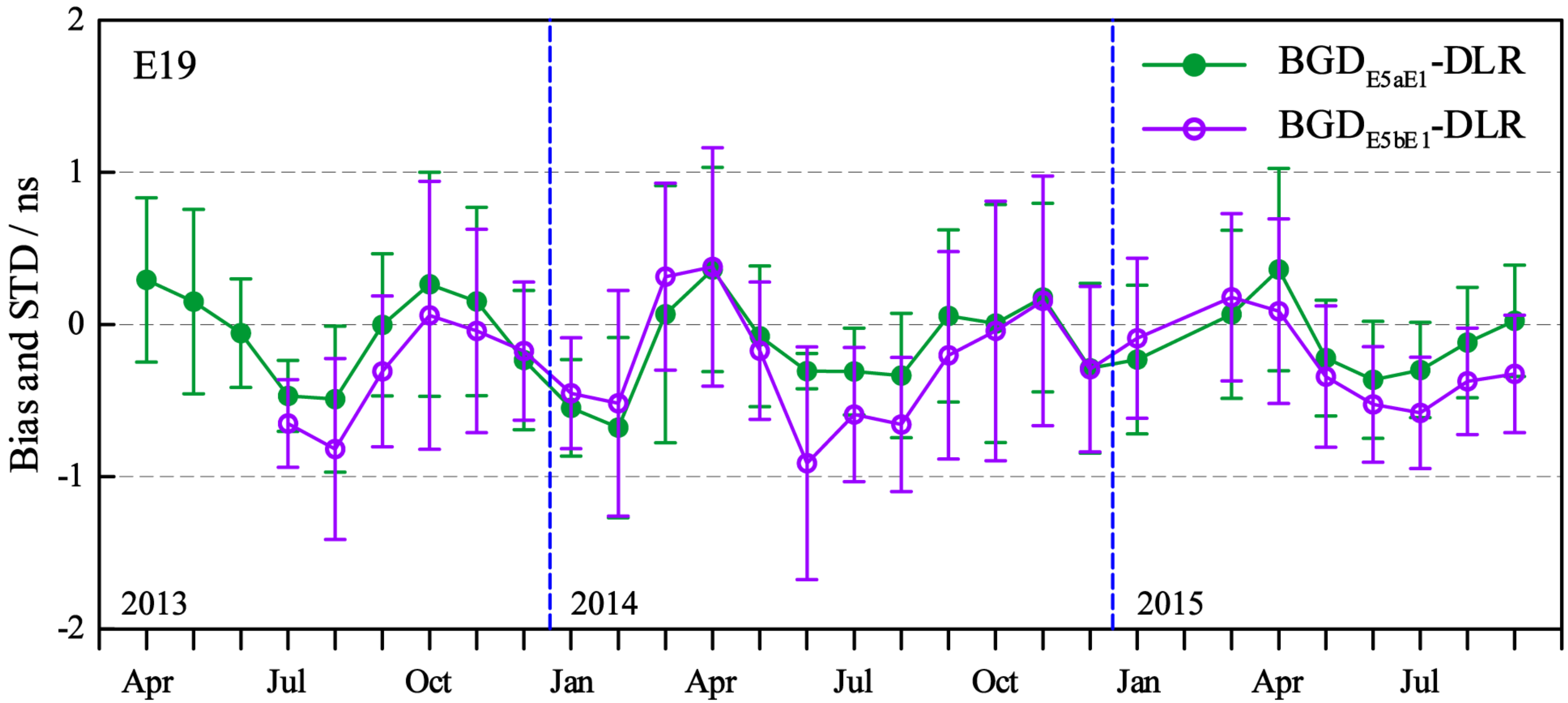
Time series of Galileo C1X-C5X, C1X-C7X and C1X-C8X DCB solutions during the period 2013-2014



RMS of the differences between Galileo DCB solutions of IGG and DLR performs at the level of 0.23 ns

Performance of Galileo BGDs

- Galileo broadcast clock offsets refer to the ionosphere-free linear combination of E5a and E1
- Broadcast Group Delays (BGD, BGD_{E5aE1} and BGD_{E5bE1}) contained in navigation message
- RMS of the differences between broadcast BGDs and DLR DCBs is 0.55 ns
- Improved broadcast BGD quality since 05/2015



Bias and STD of the broadcast BGD_{E5aE1} and BGD_{E5bE1} parameters relative to DLR DCBs for the period 2013-2015

Summary (1/1)

- Alternative DCB estimation algorithm - IGGDCB

  station-based ionospheric modeling instead of using global ionosphere maps

- Allows Multi-GNSS DCB process and analysis within MGEX network

- Routine CAS/IGG MGEX DCB products contribute to IGS MGEX project

- Good agreement of IGG DCB products with CODE/DLR DCBs (rms of differences)

  - Limits to 0.1ns, 0.2ns and 0.4ns for GPS C1C-C1P, GLONASS C1C-C1P and C2C-C2P (w.r.t CODE)
  - Performs at the level of 0.29ns and 0.56ns for GPS C1W-C2W and GLONASS C1P-C2P (w.r.t CODE)
  - 0.33ns and 0.39ns for BDS C2I-C7I and C2I-C6I DCBs, respectively (w.r.t DLR)
  - Overall agreement limits to 0.24ns for Galileo DCBs (w.r.t DLR)

- IGS and MGEX DCB products for GPS and GLONASS

  Impact of different networks and receiver types: further assessment required

Thanks for your attention.

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